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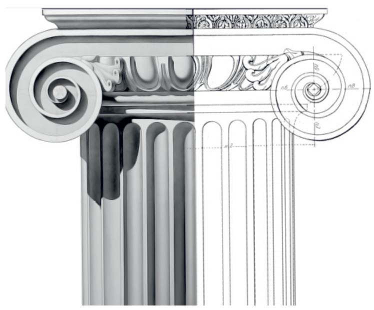

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SPECIFICS OF THE QUANTOMOBILE FORCE BALANCE

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Abstract

The article provides data on the concept of thrust forces' formation in a quantum engine (QE). Influence of difference in structural diagrams of vehicles with QEs and ICEs on their energy consumption is described. Functional differences in formation and control over thrust and speed characteristics of automobiles and quantomobiles are reviewed.

Differences in thrust balances of vehicles mentioned are analyzed. Possible topography of quantomobile regulatory characteristics is considered as well.

Keywords

Automobile, quantum engine, quantomobile, quantum thrust, force balance, regulatory characteristics.

Introduction

The opportunity of implementing non-fuel energy production ideas based on the use of the energy of the physical vacuum (Davies, 1985, Dirac, 1930, Fetta, 2014, McCulloch, 2014, Parker, 1991, Puthoff, 2010, Shawyer, 2006, Tajmar, 2018, Tesla, 2009 and others) seems more and more real. The Theory of Superunification proposed by Leonov V.S., and his quantum engine (QE) concepts formed based on that theory (Leonov, 2002, 2010a, 2010b, 2018) feature outstanding ideas and a harmonious structure.

The ability to draw energy from the global physical vacuum will result in a new technological paradigm involving the transport sector as well. Quantum engines will replace internal combustion and jet engines; the existing propulsion devices of vehicles will improve.

Previous studies of the author addressed basic provisions of the Theory of Superunification, described aspects of QE creation, predicted some features of automobiles with QEs — quantomobiles, reviewed possible stages of their studying, included a comparative computational analysis of thrust forces and energy consumption of the quantomobile and modern car (Kotikov, 2018a, 2018b, 2018c).

The present article continues expanding insights into the quantomobile concept, however, only hypothetically. The article addresses issues of the quantomobile force balance and its control.

Concept of thrust formation in quantum engines

The technology of creating the force of artificial gravitation has already been implemented by Leonov V.S. in a number of trial designs of quantum (field) engines that generate a thrust impulse due to the interaction of QE operating elements with QST (quantized space-time) without the ejection of the reactive mass (Leonov, 2002, 2010a, 2010b, 2018).

The direction and value of the force vector **F** (thrust) generated by the QE is determined by the spatial gradient (grad) of the energy W (Leonov, 2010a):

$$\mathbf{F} = \text{grad}W = \nabla W = \frac{\partial W}{\partial x}\mathbf{i} + \frac{\partial W}{\partial y}\mathbf{j} + \frac{\partial W}{\partial z}\mathbf{k} \quad (1)$$

where **i, j, k** are unit vectors along the x, y, z axes, respectively.

The modulus of force (1) is determined by the following expression (Leonov, 2018):

$$\left|\text{grad}W^2\right| = \sqrt{\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2} \quad (2)$$

The direction of the unit gradient vector (force direction) **n** is determined by the ratio of function (1) to its modulus (2) (Leonov, 2018):

$$\mathbf{n} = \frac{\text{grad}W}{\left|\text{grad}W^2\right|} = \frac{\frac{\partial W}{\partial x}\mathbf{i} + \frac{\partial W}{\partial y}\mathbf{j} + \frac{\partial W}{\partial z}\mathbf{k}}{\sqrt{\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2}} \quad (3)$$

Equations (1)...(3) are valid for calculations of the force when energy diffuses in space unevenly and energy differentials are observed, and when the function of energy distribution in space W = f (x, y, z) is known (Leonov, 2018). The Theory of Superunification provides a scientific basis for the creation of an artificial traction force (changing the direction of the force vector **n**) and thrust $\mathbf{F_T}$ (Figure 1).

Let us call the force **F** the "traction force" (denoting it as $\mathbf{F_T}$) (in terms of its application to vehicle's structural elements) as well as the "thrust force" (in terms of the field response to its perturbations in the resonator (the term is borrowed from rocketry). In case the resonator is rigidly mounted onto the vehicle's body and there are no intermediate force transducers, both things will mean the same. However, if there are intermediate transducers (dampers, reduction gears, etc.), those forces may differ.

It should also be noted that the force (vector) can be decomposed into unit vectors:

$$\mathbf{F_T} = \mathbf{F_{Tx}} + \mathbf{F_{Ty}} + \mathbf{F_{Tz}} \quad (4)$$

The scalar form of this equation is as follows:

$$F_T = \sqrt{F_{Tx}^2 + F_{Ty}^2 + F_{Tz}^2} \quad (5)$$

Influence of difference in structural diagrams of vehicles with QEs and ICEs on their energy consumption

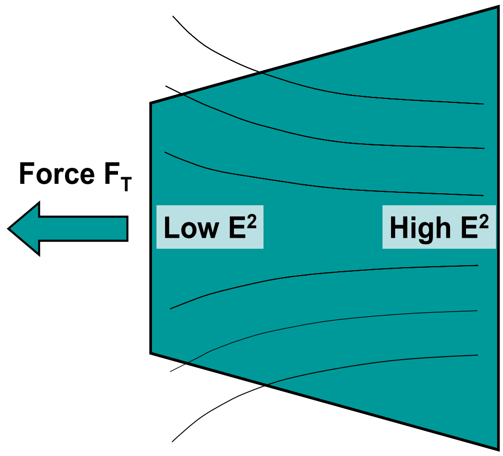

Figure 1. Gradient of field density in a QE conical resonator, resulting in thrust $\mathbf{F_T}$ formation (Brandenburg, 2016)

To estimate quantomobile power characteristics compared to those of the modern automobile, the author considered a numerical example of comparing thrust and energy consumption by a KAMAZ-4326 truck (KAMAZ-master, 2018) and a hypothetical laboratory quantomobile based on such truck (in steady movement at a constant speed of 100 km/h (27.8 m/s)) (Kotikov, 2018c).

A difference structural diagram presented in Figure 2 was developed as a conceptual basis. The calculations accounted for features of the quantomobile passive wheeled running gear and improved aerodynamics under the vehicle body.

We will use the word “vehicle” as a common name for both the automobile and quantomobile.

Short excerpts from the study calculation results (Kotikov, 2018c) are presented in the following table. In that table, G_{veh} is the weight of a vehicle with a constant load for all five options: options 1 and 2 — gross vehicle weight, 10 t; options 3 and 4 — weight reduction down to 8.8 t due to removal of the transmission elements from the design; option 5 — weight reduction by another ton due to removal of the wheeled running gear elements from the design.

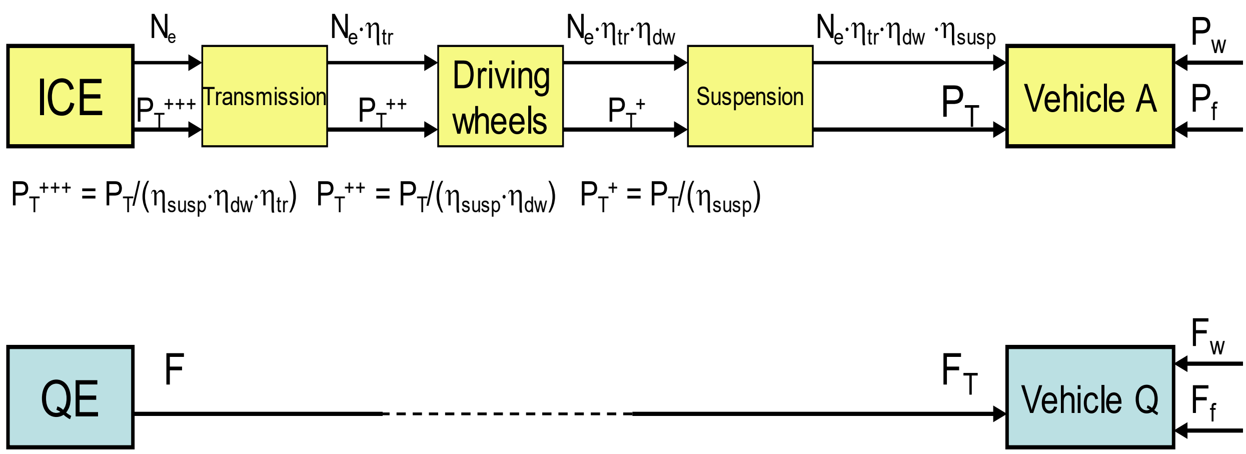

Figure 2. Diagrams of thrust generation for the automobile (Vehicle A) and quantomobile (Vehicle Q) (Kotikov, 2018c).

Table 1. Comparative calculation results.

Indicator	Design cases				
	1. Automobile, ICE, f = 0.01, P_T	2. Automobile, ICE, f = 0.1, P_T	3. Quantomobile, QE, f = 0.01, F_T	4. Quantomobile, QE, f = 0.1, F_T	5. Flying car, QE F_{Tx}
G_{veh}, N	100,000	100,000	88,000	88,000	78,000
P_T (F_T, F_{Tx}), N	4,240	13,240	3,640	11,560	1,910
N_T (N_{Tx}), kW/hp	118/160	368/500	101/137	321/437	53/72
P_e+++ (F_T, F_{Tx}), N	5,730	22,830	3,640	11,560	1,910
N_e (N_{Tx}), kW/hp	159/216.5	634/862	101/137	321/437	53/72

It is apparent that energy consumption of a quantomobile with carrying wheels at a speed of 100 km/h is 1.5–2 times less than that of a KamAZ-4326 truck (see the N_e (N_{Tx}) row of the table). Energy consumption of the flying car for the horizontal component of thrust $\mathbf{F_{Tx}}$ is three times less than that of the truck under the lowest possible resistance of the horizontal road f = 0.01 (compare columns 1 and 5 of the table).

The absence of data on energy consumption for vertical suspension of the flying car anywhere (component $\mathbf{F_{Tz}}$ of thrust (4)) made it impossible to compare the flying car with the truck in terms of total energy consumption during long-term movement under operating conditions (therefore, only the horizontal component of thrust $\mathbf{F_{Tx}}$ was taken into account).

Functional differences in formation and control over thrust and speed characteristics of automobiles and quantomobiles

Let us use well-known information related to formation of force and power balance in an automobile with an ICE as basic data for consideration of the proposed differences. As far as it is possible, we will transfer the concepts and terminology of the automobile and ICE theories to the constructed conceptual field of the quantomobile. We will apply the multi-parameter approach proposed by Soroko-Novitsky V.I. (1935, 1955) for ICEs, and by Jante A. (1958) for automobiles, which was also caught up by the author of the present paper (Kotikov, 1978, 1981, 1982a, 1982b, 2006).

The rate of energy consumption determines power of an automobile, a power unit, and is calculated as the product of the power parameter by the speed parameter. ICE power is determined by the product of the implemented engine torque M_e by the shaft speed n_e:

$$N_e = M_e \times n_e$$

Dependences of the measured torque M_e (and other parameters: position of regulatory elements, fuel supply, etc.) on speed ne are speed characteristics. The dependence $M_e = f(n_e)$ at limiting positions of the regulator is called the External Speed Characteristic (ESC). In case the ICE speed limits are achieved, the ESC changes into the Limit Regulatory Characteristic (LRC). Speed characteristics measured at intermediate positions of the regulator are Partial Speed Characteristics.

Figure 3 presents a set of speed characteristics for the KAMAZ-740 diesel engine with a two-mode regulator, measured with the participation of the author (Kotikov, 1982a, 2006). If the values of the fuel injection pump rack position h_r are placed on the orthogonal Z-axis (in the direction towards the reader), then we will obtain a three-dimensional representation of the dependence $h_r = f(M_e \times n_e)$.

It is possible to perform similar actions for fuel supply q_c and other engine parameters. Thus, based on parameters M_e (on the X-axis) and n_e (on the Y-axis), the multi-parameter characteristic of the ICE is plotted, being its functional specification. Force, speed and power indicators develop kinematics and dynamics of vehicle motion by means of the transmission and wheeled running gear.

Those dependencies forming the basis for force, power and energy balance of the automobile and its power train are provided to state that they are not needed in case we use a QE. There is no kinematic link between the speed and load modes in the power unit.

In case of a QE, things are different, and, probably, easier: there is a thrust vector applied to the vehicle design, which is to be controlled (besides, most likely, there will be nothing else to control). However, as we will see below, control over the automobile thrust balance in the estimated field $(M_e \times n_e)$ can be compared with control over the thrust vector (thrust) in a QE in the estimated field $(F_T \times V_q)$.

As QEs have no speed mode in principle, the thrust balance equation remains the main means of calculation and basis for control:

$$F_T = F_f + F_i + F_v + F_j = F_\psi + F_v + F_j \quad (6)$$

Analytical capabilities of equation (6) are graphically presented in Figure 4 that shows a comparison for the automobile (in black) and quantomobile that inherited its properties (weight, shape, etc.) (in blue).

In case of force calculations, driving conditions in terms of the clutch are usually limited by the F_{Tmax} force at φ = 0.8 (Selifonov, 2007); besides, the *GG* hyperbola enveloping the thrust force diagrams (corresponding to transmission speeds) is plotted from above, from the level of φ = 0.8 In case of a quantomobile, acceleration is not limited by the wheel grip. Figure 4 shows the force limit as the F_{Tmax} constant force (at φ = 1), which corresponds to 1g acceleration at the initial acceleration rate.

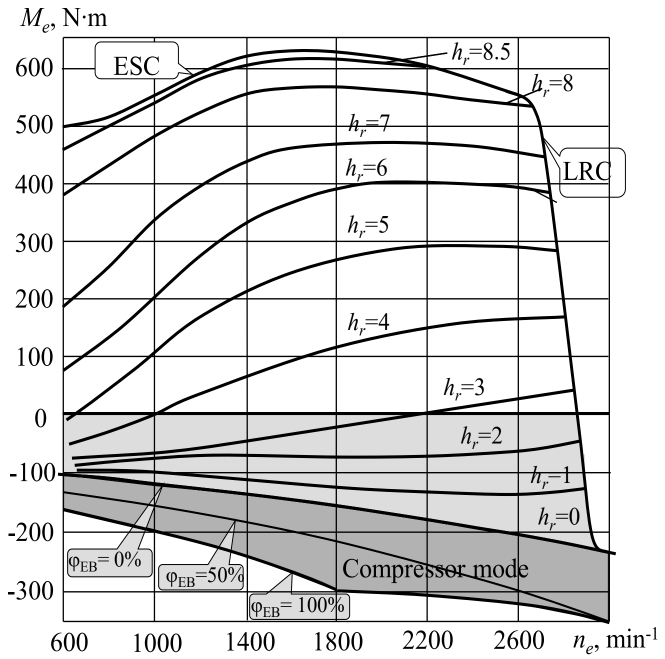

Figure 3. Set of speed characteristics M_e=M_e (n_e) of the KamAZ-740 engine according to the position of the fuel injection pump rack h_r (in mm), φ_{EB} — positions of the engine brake valve (Kotikov, 2006).

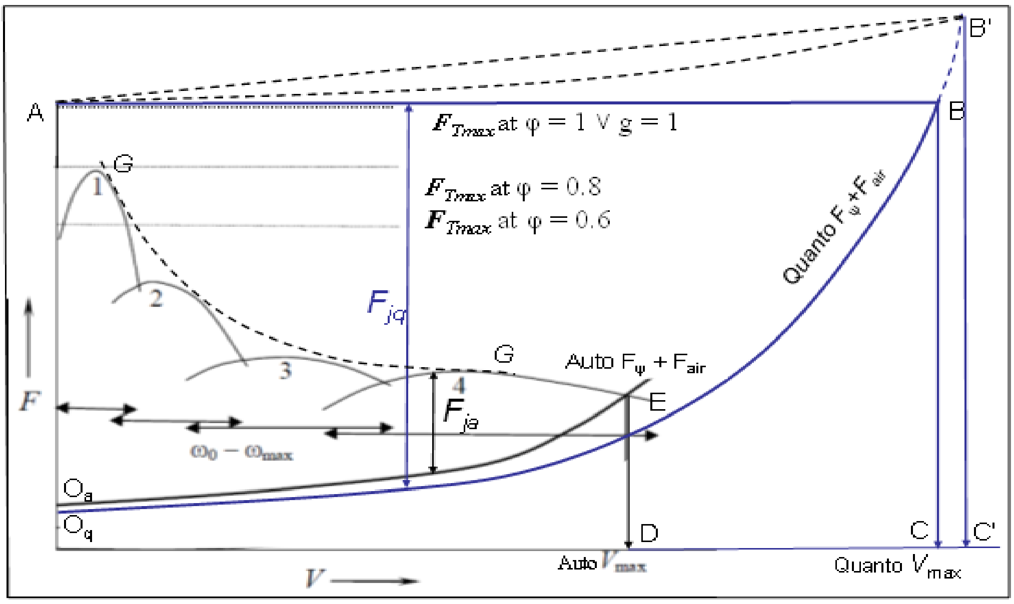

Figure 4. Thrust balance of the automobile and quantomobile.

It is obvious that the automobile has the remainder of the thrust force F_{ja} for the dynamics, whereas the value of the F_{jq} component in the quantomobile is several times larger than F_{ja}.

Moreover, lower consumption of the thrust force in a quantomobile for wheels' rolling and overcoming air resistance (F_ψ + F_{air}) (see O_aE и O_qB curves), as well as the F_{Tmax} constant force (see blue AB horizontal) result in the maximum acceleration rate of quantomobile (X-coordinate C of the contact point of curves B) which is much higher than the maximum automobile speed (compare points C and D).

Even greater acceleration speed C' can be achieved by increasing the thrust force (controlled thrust F_T) of the QE according to the rectilinear or curvilinear law during acceleration (see lines AB'). Thus, the two-channel (force and speed) multi-stage (chain: fuel injection pump regulator — fuel injection pump — combustion chamber — clutch coupling — gearbox — main gear — final reduction gears — driving wheels) system converting driver's control actions into the thrust force is replaced in a quantomobile by single-channel control over intensity of operating unit (resonator) operation in a QE producing the thrust force (thrust) that is directly applied to the vehicle body.

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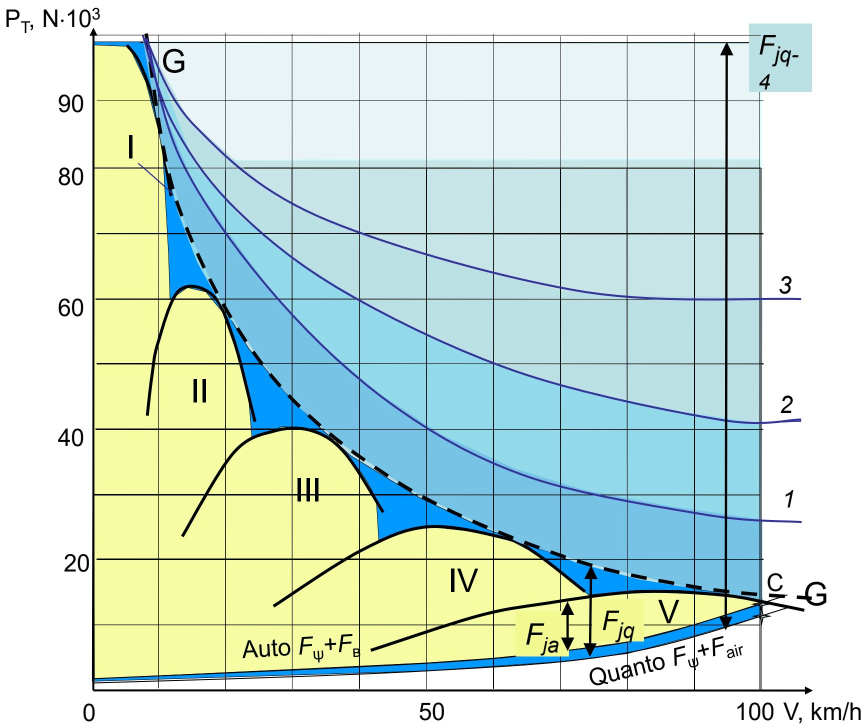

Figure 5. Thrust balance of a hypothetical automobile (yellow) and quantomobile that inherited its properties (blue) for f = 0.1: GG — a hyperbola enveloping the thrust force diagrams corresponding to transmission speeds; curves 1, 2, 3, 4 — hypothetical regulatory characteristics of a QE.

In terms of limit capabilities, the External Speed Characteristic (ESC) of the automobile ICE is replaced by the Limit Regulatory Characteristic (LRC) of the QE, which is represented by the dependence between the F scalar of the $\mathbf{F}_T$ thrust and the limit (in terms of biomechanics or due to design constraints of a controlled or autonomous vehicle) vehicle acceleration. The LRC shall be set in accordance with the current vehicle weight (rigid LRC setting in accordance with the gross vehicle weight may lead to unacceptable accelerations of the unloaded vehicle).

An overview of the thrust balance of a hypothetical automobile in the speed range up to 100 km/h is presented in Figure 5. The area of the automobile's thrust forces is highlighted in yellow. Transmission gear curves correspond to the maximum thrust efforts.Let us focus on the F_{ja} and F_{jq} forces representing the remainder of the thrust force for acceleration implementation in the automobile and quantomobile, respectively. As we can see, $F_{jq} > F_{ja}$. This can be confirmed analytically by the following equation for vehicle acceleration *a*:

$$a = (D - \psi)\frac{g}{\delta}, \tag{7}$$

where *D* — a vehicle dynamic factor;

ψ — a road resistance coefficient;

δ — a coefficient to account for inertia of the vehicle's rotating masses.

The dynamic factor $D = \left(F_T - F_{air}\right)/G_{veh}$ of the quantomobile is higher as its air resistance F_{air} is lower, and its total weight G_{veh} is lower as well. The coefficient ψ for the quantomobile is also lower (due to the absence of the wheels' driving mode).

For the automobile:

$$\delta = 1 + \delta_1 \times i_{tr}^{\ 2} + \delta_2,$$

where δ_1 — a coefficient to account for inertia of the engine and transmission rotating masses, whereas δ_2 — a coefficient to account for inertia of the rotating wheels. Since the quantomobile has no engine and transmission rotating masses, in this case the equation term $\delta_1 \times i_{tr}^{\ 2}$ drops out; besides, the δ value in equation (7) is always lower for the quantomobile than that for the automobile.

Thus, several factors work for higher acceleration values in the quantomobile, as compared to the prototype automobile. The dotted enveloping GG curve represents the geometric locus of the maximum thrust forces upon arbitrary variation of the series of transmission ratios of possible automobile gearboxes; this also reflects an option of using a variator with continuous changes in the transmission ratio.

If we consider the enveloping GG curve as a regulatory characteristic of quantomobile thrust, we will obtain an option of quantomobile movement with the structural load equivalent to that of the prototype automobile. Let us now focus on the F_{jq} force. It is larger than the F_{ja} force (mainly due to the lower values of wheels' rolling and air resistance). That means that the quantomobile can move with greater acceleration as compared to the prototype automobile.

Hyperbolas 1, 2, and 3 can act as QE regulatory characteristics for implementation of acceleration values much higher than those of the prototype automobile. The hyperbolic nature of those curves corresponds to the tendency towards vehicle acceleration decrease at high speeds, i.e. implementation of "carefulness" in terms of traffic safety. It would be possible to select those based on the operation conditions. Straight line 4 represents the QE Limit Regulatory Characteristic corresponding to the QE limit capabilities (if thrust augmentation AB' is not introduced (see Figure 4)).

Concerning topography of quantomobile regulatory characteristics

It is hard to tell how sophisticated the QE F_T thrust regulator can be. But one thing is already clear — the Basic Regulatory Characteristic/Curve (BRC) will inevitably exist, represented by a framework for converting driver's (or automatic machine's) control actions into implementable thrust values:

$$L = f_L\left(F_T, V_q\right), \tag{8}$$

where L — position of the driver's control lever.

It is also possible to use reverse functional (and graphical) representation:

$$F_T = f_F(V_q, L) \tag{9}$$

The Basic option implies that there is no account for hysteresis, no regulators (PID-, LQR-, Fuzzi- or others), as well as correctors (direct and reverse ones used to remove rigidity in the angles of the regulatory characteristic).

Taking the regulatory characteristic of a centrifugal two-mode regulator (Figure 3) as a prototype for BRC graphical plotting, we will make similar plottings for the BRC (Figure 6a).

Let us outline features of those BRCs. The convex nature of the curves in the two-mode ICE regulator (see Figure 3) can be explained by the non-linear convex nature of the engine torque speed characteristics (which, in turn, depend on non-linear convexity related to the efficiency coefficient within the engine operation field).

As the QE conversion coefficient CC (substituting the efficiency coefficient for a QE) is independent of the quantomobile speed mode (and due to the absence of specific QE characteristics), the two-mode regulation nature can be represented in the BRC by a series of horizontal lines (blue lines).

The ICE compressor mode during engine braking is represented by a set of curves close to horizontal lines (see the lower part of Figure 3). The angles of curves' deviation from the horizontal and their nonlinearity can be explained by the dependence of resistances to air flow in intake and exhaust systems on the speed mode. Since QEs have no such dependence, it is reasonable to represent the braking BRCs with a series of horizontals (red lines).

The regulatory characteristics of the thrust and braking modes meet on the line ($F_\psi + F_{air}$) (see Figure 5) as in the absence of thrust the vehicle begins to slow down precisely on this line. This line also represents the boundary between the thrust zone (light blue) and braking zone (pink). For the purposes of understanding and comparison, the area of thrust modes of the prototype

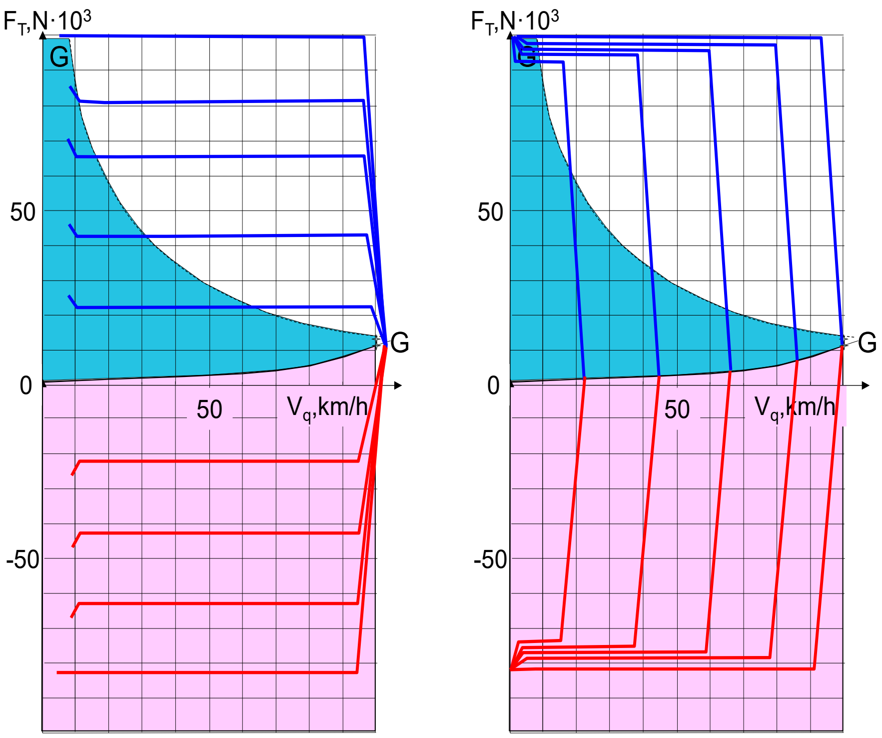

Figure 6. Basic regulatory characteristics of the quantomobile:
a) two-mode; b) multi-mode

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automobile (transferred from Figure 5) is also marked with blue.

Figure 6b shows the multi-mode BRC. This type of regulation is applicable for cruise control when it is necessary to maintain a relatively constant speed independent of changes in road resistance. Besides, in the absence of specific data on QEs (and at the start of their emergence), the curves are straight. The author provided for the mirror-like curves in the braking zone (pink) (in relation to the curves of the thrust zone (blue)). Most likely, in practice, there will be no such mirror reflection. Moreover, combination of the two-mode and multi-mode topology of the set of curves for the same QE is possible.

Conclusion

Quantum engines and quantomobiles are still far from modern realities and capabilities. The key problems are associated with development of the physical vacuum.

The author believes that the present study approaches such development. Indeed, it is useful to evaluate capabilities of those fuzzy objects, as well as their hypothetical features and principle of control, in advance.

References

Brandenburg, J. (2016). *GEM theory of Q-V Thruster.* Available at: http://ssi.org/wp-content/uploads/2017/02/ssi_estes_park_proceedings_201609.pdf. (accessed on: 12.01.2019)

Davies, P. (1985). *Superforce.* New York: Touchstone.

Dirac P. (1930). *The Principles of Quantum Mechanics.* Oxford: The Clarendon Press.

Fetta, G. (2014). *Electromagnetic Thruster. Patent US 2014/0013724 A1.* Available at: http://www.rexresearch.com/fetta/US2014013724A1.pdf (accessed on: 12.01.2019)

Jante, A. (1958). *Mechanics of car movement,* part 1. Moscow: Mashgiz.

Kotikov, J., Budyko, Yu., Lisitsyn, A. (1978). Use of modified universal characteristics for evaluation of fuel injection equipment of car engines. In: *Proceedings of the Central Research & Development and Design Institute of Fuel Injection Equipment for Automotive and Stationary Engines*, 71, pp. 62–67.

Kotikov, J., Lukin A. (1981). Necessity to evaluate the automobile engine service features on its summarized and specialized service condition. *Dvigatelestroyeniye*, 3, pp. 45–47.

Kotikov, J.G., Gorev, A.E., Mamin, B.V., Shestakov, A.A. (1982a). Experimental evaluation of speed as well as fuel economy properties of a heavy-duty road train with two fuel injection pump options. *Dvigatelestroyeniye*, 10, pp. 46–47.

Kotikov, J.G. (1982b). Structure of the system for formation of estimates for performance of mobile machine engines. *Dvigatelestroyeniye*, 5, pp. 37–40.

Kotikov, J. (ed.) (2006). *Transport power energy.* Moscow: Academia Publishing Center.

Kotikov, J. (2018a). Structural properties and operational philosophy of the vehicle with the quantum engine. *Architecture and Engineering*, 3 (1), pp. 13–20. DOI: 10.23968/2500-0055-2018-3-1-13-20.

Kotikov J. (2018b). Stages of Quantomobile Development. *Architecture and Engineering*, 3 (2), pp. 26–35. DOI: 10.23968/2500-0055-2018-3-2-26-35.

Kotikov J. (2018c). Comparative Analysis of Energy Consumption by Modern Cars and Future Quantomobiles. *Architecture and Engineering*, 3 (4), pp. 24–30. DOI: 10.23968/2500-0055-2018-3-4-26-32.

Leonov, V.S. (2002). Patent No. 2185526 (Russian Federation). *A method of thrust generation in vacuum and a field engine for spaceship (options)*. Bulletin No. 20 dd. 20.07.2002 (priority date: 21.05.2001).

Leonov, V.S. (2010a). *Quantum Energetics. Volume 1. Theory of Superunification.* Cambridge: Cambridge International Science Publishing.

Leonov, V.S. (2010b). *Space: Quantum Engine Test Results Regarding Thrust Generation Without Ejection*. Available at: http://www.astronomy.ru/forum/index.php/topic,77730.0.html (accessed on: 28.01.2018)

Leonov, V.S. (2018). *Fundamentals of physics of a reactive thrust and nonreactive thrust]*. Moscow: Amrita.

McCulloch, M. (2014). *Physics from the Edge: A New Cosmological Model for Inertia*. Singapore: Wspc.

Parker, B. (1991). *Einstein's Dream. The Search for a Unified Theory of the Universe.* (translated from English by V. I. Matsarskikh and O. I. Matsarskikh). Moscow: Nauka.

Puthoff, H. (2010). Advanced Space Propulsion Based on Vacuum (Spacetime Metric) Engineering. *JBIS*, 63, pp. 82–89.

Selifonov, V.V., Khusainov, A.Sh., Lomakin, V.V. (2007). *Automobile theory: study guide*. Moscow: Moscow State Technical University “MAMI”.

Shawyer, R. (2006). *A Theory of Microwave Propulsion for Spacecraft.* Available at: https://www.newscientist.com/data/images/ns/av/shawyertheory.pdf. (accessed on: 14.01.2019)

Soroko-Novitsky, V.I. (1935). *Tests of automobile engines: fundamentals of the theory of measurement instruments, units for testing automobile engines, and mathematical processing of test results.* Leningrad: Printing House named after Evgeniya Sokolova.

Soroko-Novitsky, V.I. (1955). *Tests of automotive engines.* Moscow: Mashgiz.

Tajmar, M., Kößling, M., Weikert, M., Monette, M. (2018). *The SpaceDrive Project – First Results on EMDrive and Mach-Effect Thrusters*. Available at: https://tu-dresden.de/ing/maschinenwesen/ilr/rfs/ressourcen/dateien/forschung/folder-2007-08-21-5231434330/ag_raumfahrtantriebe/SPC-The-SpaceDrive-Project-First-Results-on-EMDrive-and-Mach-Effect-Thrusters.pdf?lang=en. (accessed on: 14.01.2019)

Tesla, N. (2009). *Patents*. Samara: Agni Publishing House.

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EVOLUTION OF THE IMPERIAL RESIDENCE AND URBAN DEVELOPMENT OF THE ST. PETERSBURG CENTER

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Abstract

The scale and nature of the impact of the imperial residence in St. Petersburg on the urban environment of the city center are considered. It is noted that St. Petersburg was a residence city for two centuries, which significantly affected its development. It is emphasized that the Winter Palace was not considered the center of city-planning composition of citywide significance, but gradual development of the residence according to the growing needs of the imperial family had decisive effect on formation of a large area in the historical nucleus of the city.

Periodization for evolution of the area and imperial palace complex is suggested. It takes into account changes in its location in St. Petersburg and its functions, and clearly demonstrates that the culmination of their development was in the first third of the 19th century. It is noted that the area of the imperial residence is currently considered to be the core of the historical city center, but the conditions for adequate grasp of its unique landscape have been constantly deteriorating due to the growing traffic flow in the city. It is recommended to consider the possibility of creating convenient observation platforms on roofs of buildings and in the Neva water area.

Keywords

St. Petersburg center, city-planning processes, imperial residences, landscapes.

Introduction

The reviewer of the initial version of this article advised to give more attention to the definition of the "residence city" term. And he had every reason for that. Since the end of the 18th century the interpretation of this notion has presented a challenge. In one of the first guide books on St. Petersburg published in 1790 in German, St. Petersburg was called "a Russian imperial **residence-city**" ("Rußisch-Kayserlichen Residenzstadt") (Georgi, 1790), and in a new edition published in 1794 in Russian, it was called "a Russian imperial **capital city**" (Georgi, 2001).

Modern Russian Wikipedia provides only a brief information that "a residence (Late Latin residentia) is a place where the head of the state or government, an ambassador of a foreign state resides") (https://dic.academic.ru/dic.nsf/enc3p/253230).

In German, a residence-city is a settlement where the monarch resides. In such city, the monarch demonstrates to its subjects and representatives of other states his/her power, which is expressed both in architecture (in particular, in palaces and public buildings) and symbolic events (holidays, processions, parades, royal ceremonies). A residence-city shall represent the power of order and stability in the state (https://de.wikipedia.org/wiki/Residenzstadt).

The Russian science views residence-cities as a special type of cities. Authors of papers on art history, studying image and aesthetic characteristics of cities as reflection of worldviews, aesthetic preferences and political intentions of the rulers, take an interest in their specifics most often (Kirichenko, 1997a; 1997b; Petrova, 2006).

In this article, we take as a premise that synonyms of the word *"rezidentsia"* (residence) in the New Explanatory Dictionary of Synonyms of the Russian Language (Levontina, 1995) are *"dom"* (house), *"zhilische"* (dwelling), *"zhilploschad"* (living space)". The impact the imperial residence had on city-planning processes in St. Petersburg is considered at the application level. It is recognized that Russian sovereign rulers had exclusive powers. Russian tsars were considered "the masters of the Russian land" since the 17th century (https://dic.academic.ru/dic.nsf/dicwingwords/). The tsar could both guide the strategy of the city-planning policy and set specific tasks related to the residence development in person.

During two centuries, a quite developed system of facilities intended to care for the monarch's family formed in St. Petersburg and the surrounding area. Table 1 presents those that were official residencies of Russian emperors.

It would be interesting to examine how the development of the central part of the city changed under the influence of the evolution of the imperial residence.

Along the Fontanka River — the Summer Garden area

The habitable territory of the former manor of a Swedish officer near the expansion of Neva and Fontanka was chosen as a place for a summer imperial residence as early as right after the official foundation of St. Petersburg. In 1712, to celebrate Peter the Great's wedding, a small palace was built on the relatively dense land near Neva, and Catherine the Great's manor house was built to the South, beyond the Moyka River. In 1719, to dry a nearby swampy flat land, the Krasny (Red) Canal and the Lebyazhya (Swan) Canal were dug. In 1725, the Hall for Glorious Ceremonies was built on the Neva bank in the Summer Garden.

The large area became a focus of active transformations that took place after the return of the imperial court from Moscow. In 1732, the luxurious Anna Ivanovna's Summer Palace replaced the demolished Hall for Glorious Ceremonies. At the same time, in the third Summer Garden (where swampy hunting lands of a Swedish officer were previously located), "a jagd garden to chase and shoot deer, wild boars and hare" with a gallery and stone walls "to prevent bullets and shots from flying in" (Ivanova, 1981) was arranged for the august huntress. In the 1740s, the Summer Garden was a ceremonial imperial residence. A special permit was required to enter the garden (http://www.citywalls.ru/house15390.html?s=r0j8f4gfe3l7fce5jmctqd7qk6). In 1740, implementation of a new large-scale project that would meet Anna Leopoldovna's wishes started. Catherine the Great's "Golden Mansion" was demolished, and a summer palace was built to the South of the Moyka River, while the representative Promenade garden was arranged on the dried land of the future Marsovo Polye (Dubyago, 1963).

When Elizabeth Petrovna became enthroned, everything changed once again: in 1748, Anna Ivanovna's palace on the bank of Neva was demolished, and a regular garden with boskets, summer houses and ponds appeared in the place of the jagd garden. Traces of the Promenade Garden were lost in historical records. The residence palace was finished to meet the taste of the new Empress, and it became known as Elizabeth Petrovna's Summer Palace (http://rusmuseumvrm.ru/data/collections/painting/17_19/neizvestniy_hudozhnik_letniy_dvorec_elizaveti_petrovni_tretya_chetvert_xviii_veka_z_3132/index.php).

Table 1. Imperial residences in St. Petersburg.

Regnal years, the ruler	Winter residence	Summer residence
1703—1725, Peter the Great	"Cabin of Peter the Great" on the Petrograd Side	
	Winter House (since 1708) Wedding Chambers (since 1712) The first Winter Palace (since 1720)	Summer Palace (since 1712) Catherine the Great's "Golden Mansion" (since 1712)
1725–1727 Catherine I	The second Winter Palace	Hall for Glorious Ceremonies
1727, Peter II	Menshikov Palace (1727), Moscow (1728–1730)	
1730–1740, Anna of Russia (Anna Ivanovna)	Moscow (1730–1732), the second Winter Palace (1732–1735), the third Winter Palace (1735–1740)	Anna Ivanovna's Palace in the first Summer Garden with the "Jagd Garden" in the third Summer Garden (1732–1740)
1740–1741, regentess Anna Leopoldovna (Emperor Ivan IV)	Summer Palace of Peter the Great	Summer Palace of Peter the Great
1741–1761, Elizabeth Petrovna (Elizabeth I)	Third Winter Palace (1741–1755), the Fourth (temporary) Winter Palace where Mytny Dvor is located (1755–1761)	Summer Palace of Elizabeth Petrovna
1761–1762, Peter III		
1762–1796, Catherine the Great	The fifth Winter Palace	
1796–1801, Paul I	Winter Palace (1796–1801)	
	Mikhailovsky Castle (1801)	
1801–1825 Alexander I of Russia	Winter Palace	
1825–1855, Nicholas I of Russia	Winter Palace	
1855–1881, Alexander II of Russia	Winter Palace	
1881–1894, Alexander III of Russia	Anichkov Palace	
1894–1917, Nicholas II of Russia	Anichkov Palace (1894), Winter Palace (1895–1904)	

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When Catherine the Great became enthroned, the interest of reigning monarchs to the Summer Garden area faded. New emperors preferred suburban palace and garden complexes as a place of their residence in summer.

The area on the Fontanka River bank once again became an object of interest for a short period of time in the end of the 18th century. The luxurious Elizabeth Petrovna's residence (by F.B. Rastrelli) was demolished promptly. Even as the heir to the throne, Paul I decided to move the imperial residence from the Winter Palace and was the one to choose the suitable place. The following decree was issued on November 28, 1796 (as early as during the first month of his reign): "to build a new impenetrable castle palace for continuous residence of the tsar. And this palace will replace the dilapidated Summer House" (Bakhareva et al., 2003).

Paul I decided that his personal residence should be similar to Medieval castles that were surrounded by channels filled with water, and that is why he believed that the area of Moyka and Fontanka was the most suitable. He started preparations for the castle environment as early as in 1797. He accommodated the Kexholm Regiment in a building on the Field of Mars, having evicted the Orphanage from there. It is known that the emperor also did not like a large wooden "Opera House" building nearby, on the Tsaritsyn Meadow... "

He ordered Mr. Arkharov, a military governor, accompanying him: "Nikolay Petrovich, please, get rid of it!" And he pointed at the theater. According to the legend, in three hours it was as if there had been no "Opera House" at all. In lantern lights, more than five hundred workers were flattening the site where it stood that day" (Sindalovsky, 2012).

By the end of 1800, a new residence complex was finished, with "das Wasserschloss" ("water castle"), untypical for St. Petersburg, being in the center. Typologically, the castle is related to the Lower Rhine fortifications made during Renaissance. Here, on a large area stretched along the Fontanka River bed, besides the palace, two guardrooms, a drill hall and a stables building were located, and in front of the gate of honor on the Connetable square — Peter the Great's equestrian monument. It is noted that the Mikhailovsky Castle "became a masterpiece of St. Petersburg architecture, but did not blend in with any art movement of its time", and its urban-planning complex can be regarded as an ancestor of outstanding ensembles that would decorate St. Petersburg in the first third of the 19th century (Lisovsky, 2004).

The Mikhailovsky Castle served as a residence for a little more than a month only. After the death of Paul I, the imperial family tried to forget about this building, and there were no new ideas on developing the complex in the Summer Garden area. The unpaved Field of Mars became famous for its clouds of dust raised by marching soldiers, and known as St. Petersburg Sahara. The interest towards this area increased in the beginning of the 20th century when the imperial residence moved to the Alexander Palace in Tsarskoye Selo and autocratic rule was transformed into the Duma monarchy (http://lawtoday.ru/razdel/biblo/igipr/088.php). In the shortest time possible, a proposal to build a huge State Duma building on the Field of Mars was made, and relevant bidding was arranged (Bass, 2009).

The Winter Palace area — along the Neva River

Peter the Great chose the area for his first winter residence on the Neva bank in the Admiralty Part, having taken into account various considerations:

- the critical role of the central water area of Neva in shaping the image of a capital city was highlighted. This concept was supported by the Peter and Paul Fortress with a high bell tower of the cathedral, located on the other river bank, and the 400-meter long facade of the Twelve Collegia building facing the Neva expansion;
- the Tsar could view from this place both important construction sites of the new city and navigable passes of Bolshaya Neva and Malaya Neva that were of strategic importance;
- from here it was possible to reach other parts of the city by water, and if travelling by land, the distance both to the Summer Garden and the Admiralty was less than one kilometer.

Peter the Great did not pay any attention to the dignified appearance of his residence: his Winter House is near other structures on the Neva bank and does not particularly stand out. Naturally, when making plans for "the capital city of St. Petersburg", he did not raise any questions related to the location of the imperial palace. Peter the Great's standing also affected further development of the central part of the city: the Admiralty, rather than the imperial residence, became the dominating element of its urban arrangement.

The Winter House on the Neva embankment became larger, was rebuilt and transformed into the Winter Palace by 1723. After Peter the Great's death, this building was radically upgraded by order of Catherine I.

In the 1730s, the city became deserted, and the fires in 1736 and 1737 destroyed more than a half residential houses on Admiralteysky (Admiralty) Island. However, Peter the Great's successors did not make any attempts to move the residence to another part of the city, which attracted court noblemen, high-ranking public officials and their associates and contributed to active development of the southern bank of Neva.

When Anna Ivanovna moved to St. Petersburg, it was decided to enlarge the imperial residence and develop it further to the west of the Zimnyaya (Winter) Canal that had been dug out by that time. Houses owned by Apraksin, the Maritime Academy and Chernyshev were bought out and demolished, and the third Winter Palace was built in their place in 1732–1735. The facade facing Neva was regarded as the front one, and extra technical structures, sheds and stables were built at the back of the building (https://ria.ru/culture/20090627/175487226.html).

By the mid-18th century, this complex "was mottled and dirty and unworthy of the place it occupied, and the very oddity of the imperial palace adjacent to the Admiralty on the one side and to the decrepit Raguzinsky's chambers on the other side could not be pleasant for the Empress".

In 1752, Elizabeth Petrovna ordered architect Rastrelli to enlarge the residence and make it more presentable, and for that reason huge size of the designed complex was set (in plan: 210x175 m, height — 23.5 m). Neighboring land plots were bought out, and construction works started in 1754. It was Peter III who accepted the completed works in April 1762, and in the summer of 1762 he was dethroned. Catherine the Great became the owner of the palace (Zimin, 2012). She immediately saw its true urban value.

I.E. Grabar (1910) thought it necessary to attract special attention to the activities of Catherine the Great and Alexander I to develop St. Petersburg and called them custodians of Peter the Great's heritage. He did not see "the noble passion for construction (the passion of the Medici, Julius II, Peter the Great and Catherine the Great), this "obsession with architecture", the inexpugnable desire to build, build and build" in many European rulers, but he qualified these Russian rulers as noble sovereigns who made their mark on the world through their city-planning activities and largely defined the image of St. Petersburg.

Catherine the Great established the leading role of the Winter Palace in urban development of this part of the city and paid special attention to its engagement with the Neva water area. The works started when in 1764–1768 wooden slopes that fenced the Neva bank in front of the palace were replaced with a bearing structure. However, the width of the new embankment was considered to be too small, and in 1772–1773, the embankment was rebuilt, with the granite wall significantly outreaching to the water area (Frolov, 2005).

Attention was also paid to the adjacent buildings: the Empress decided to enlarge the residence and erect new buildings to replace the adjacent dilapidated ones. This complex became an experiment in implementation of settings used for development of city blocks: "All houses to be located on the same street should be built as one solid facade with the doorsteps not coming out to the street and the same height along the building line" (Bunin, Savarenskaya, 2017). The facades of the Winter Palace, Hermitage, Old Hermitage became joint, and the Hermitage Theater joined them soon.

At the time, two-story buildings prevailed on the Neva embankments, but for new buildings of the imperial residence, the height of 22 m was set in 1765 (it was a

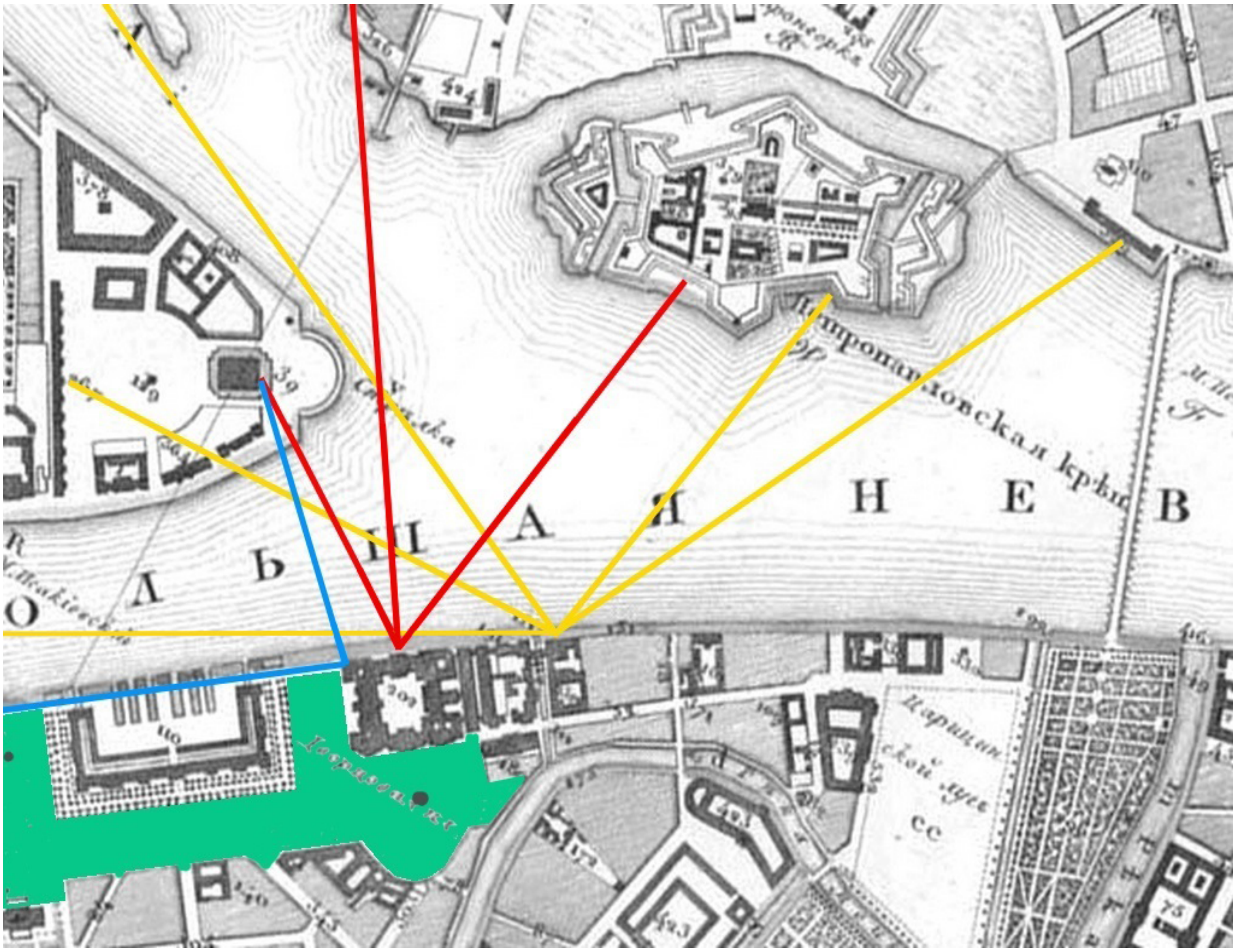

Figure 1. Establishment of the Winter Palace area. Lines of sight are shown in colored lines: yellow — Peter the Great, red — Catherine the Great, blue — Alexander I. The area of the ensemble of central squares is highlighted in green.

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bit lower than the eaves of the Winter Palace), so that "buildings on Neva at least a little bit corresponded to the stone bank created along the river" (Bunin, Savarenskaya, 2017). A single front of representative palace buildings with the height of 22 m and the length of 400 m formed on the Palace Embankment. The city-planning direction related to the use of grand buildings, set by Peter the Great at the construction of Twelve Collegia and the Admiralty with 400 m long facades, Gostiny Dvor with 700 m long perimeter, and Peter and Paul Cathedral with a 112 m long spire, was continued. The southern side of the main Neva water area got decent borders.

However, this was not the end. Such parts of the Neva panorama as the gloomy Spit of Vasilyevsky Island and the Petrograd Side that at the time was regarded as outskirts came into the view of the Empress. Their image was not in harmony with the respectable Palace Embankment, and in 1766–1773, by order of Catherine the Great, the Prince Vladimir Cathedral, the unfinished building of which had been seen from the windows of the Winter Palace since 1742, was reconstructed, and in 1779–1785, brick walls of the Peter and Paul Fortress were faced with stone. In 1783, according to the design by Giacomo Quarenghi, construction of a stock exchange started, but the empress was not impressed with the building, and the construction was put on hold.

Paul I thought that the Winter Palace was not suitable for residence and planned to arrange for barracks there (as he did with the Tauride Palace) (Zimin, 2012), and that is why he upgraded fortifications of the Admiralty Fortress near the palace. All financial resources were directed to construction and finishing of the Engineers' Castle.

I.E. Grabar pays special attention to Alexander I who became the emperor in the first year of the 19th century, since "Alexander was a direct successor of the Catherine the Great's work, and his passion for construction was not less than that of his grandmother". Alexander I confirmed the role of the Winter Palace as the imperial residence, but he moved his closet to its western part (Zimin, 2012), which played a noticeable role in urban development of St. Petersburg.

Alexander I, like Catherine the Great, paid great attention to the view from the windows of the residence. As early as during the first year of his reign, he noticed an unfinished building of the stock exchange on Vasilyevsky Island and decided to overhaul it. This work was assigned to Jean-François Thomas de Thomon. It was a small facility (central trading floor of the stock exchange had the area of 900 sq. m.), but the project quickly became a city-planning event of strategic importance.

Applied considerations were relegated to the background, and the main objective was to improve the aesthetic qualities of the landscape of the "central Neva area". I.E. Grabar notes that "...under Alexander's reign, the main task was to build something large, grand, festive", since "he wanted to make St. Petersburg more beautiful than all the European capitals he visited" (Grabar, 1910). It is obvious that since 1804, the complex on the Spit was considered a key facility in implementation of this idea.

Outstanding architects D. Zakharov, G. Quarenghi, I. Lukin and (according to some assumptions) C. Rossi worked on the project. Large volumes of construction works and manufacture of numerous art objects were financed. A soil mass was filled into water to make a semicircular site of more than 150 m in diameter. Two Rostral Columns, 32 m high and decorated with sculptures, appeared on the Spit. Under each of them was a stone foundation platform buried 5 m deep with dimensions in plan of 18x21 m, and a field of piles with the length of 6 m (Lavrov, Perov, 2016). Granite embankments stretched over 600 m.

The works on the project continued even after the death of Alexander I, when the Collegiate square formed between the Twelve Collegia building and the Stock Exchange, and "one of the most beautiful ensembles of Old St. Petersburg" appeared (Lisovsky, 2004). The expenses for the aesthetics of the Spit paid off: the landscape of the "central Neva area" as viewed from the windows of the Winter Palace was completed and became one of the symbols of the Russian capital.

Winter Palace area — to the Admiralty Meadow

As for the Admiralty Part area adjacent to the Winter Palace from the west and south, it, unlike the Neva space, did not attract attention of the reigning monarchs for a long time. Under Anna Ivanovna's and Elizabeth Petrovna's reign, the Tsaritsyn Meadow was used to store construction materials, accommodate outbuildings and tend palace cows.

For Catherine the Great, the view from the windows of her closet facing the Admiralty Meadow was not so important: she just ordered to start paving it, and, "by the end of the reign of Catherine the Great, the Admiralty Square became paved, albeit poorly" (Stolpyansky, 1923). Three buildings appearing in 1788 near the Winter Palace formed a small semicircle, which gave the contemporaries grounds to compare the square with an "amphitheater" (Georgi, 2001). It did not attract special attention.

The neighborhood of the imperial residence with the Admiralty shipbuilding manufacture could raise conflicts due to the noise and smell of tar carried by the western winds. However, only after 1782, when a disastrous fire happened in the shipyard, that could easily spill over to the Winter Palace, the scared empress thought that it would be better to move the shipyard to Kronstadt, farther from the palace. The implementation of the idea required time and a lot of money (the Admiralty collegium presented an estimate for 9 million rubles), and that is why it was put into cold storage (http://www.ipetersburg.ru/admiralteystvo).

For Alexander I, the aesthetics of the buildings adjacent to the palace were of interest. In 1805, a contemporary of the time described "wild and sorrowful disharmony of the Admiralty that due to the height of the earth mound also seemed lower and darker: the view of that discordant scene was unbearable... and it was possible to stare only at one golden spire of the middle tower, inviting to the eye. The considerate emperor surely saw the need for reconstruction of this important building!". The shipbuilding manufacture was moving from the Admiralty to a new place, opening good prospects, but financial limitations appeared: "since the times of Empress Catherine the Great, "reasonable economy" has been in greatest request" (Kurbatov, 1913). A lot of money was spent on the Stock Exchange complex, that is why austerity measures were taken for reconstruction of the Admiralty. The author of the concept A.D. Zakharov wrote: "During the development of this draft project, my first rule was to secure benefits for the Treasury. Therefore, I decided not to break old walls and foundations, and that is why only several bare walls were added..." (Sashonko, 1982).

However, when in 1808 the emperor found that the reconstructed and roofed Admiralty building "overlaps with the view from his own chambers on the Galernaya Harbor and the Neva mouth", they had to settle for large costs, demolish the newly built walls adjacent to Neva, and overwork the entire project (Shuysky, 1989) (the demolished area is highlighted in blue in the 1808 layout (Figure 2)). Cost savings were once again a decisive factor when in 1817 the fate of the Admiralty Fortress canals was discussed. A.D. Zakharov wanted to make them look impressive as the Moyka embankments, but it was decided not to spend money and to fill up the canals (Frolov, 2005).

As a result, after the reconstruction, there was a system of squares near the Admiralty, covering this huge complex in a semicircle and naturally merging with the Neva water area. It is obvious that by the end of the first third of the 19th century, the imperial residence area in St. Petersburg reached its climax (Figure 2).

The scale of a huge open space in front of the southern facade of the Winter Palace was impressive: its length was twice the length of the Field of Mars (Figure 2, 1830 layout). A huge ground was an ideal place for ceremonial military parades that distinguished the epoch of Alexander I and Nicholas I who inherited their passion for beautiful military ceremonies from their father. "The St. Petersburg parade was a manifestation of the state and imperial power, and with its visual appeal it decorated the festive space and brought it to the level of the main ceremonial square of the empire" (http://www.peterburg.biz/voennyie-paradyi-i-tseremonii-blesk-traditsiy-i-istorii.html#ixzz5YHJkNWeU).

During the reign of Nicholas I, the area, free after the demolition of the Admiralty Fortress fortifications, with the length of about 100 m, between the Winter Palace and the Admiralty turned into the Razvodnaya ground used for palace guard mounting. "Almost by the end of the 19th century, a ceremony of guard mounting initiated by Peter III, that was conducted twice a year (in the spring — at the ground between the Admiralty and the Winter Palace, and in the winter — in the Mikhailovsky Manezh) was in the list of military official traditions" (http://www.peterburg.biz/voennyie-paradyi-i-tseremonii-blesk-traditsiy-i-istorii.html#ixzz5YHJkNWeU). The place was very popular with townsfolk.

People were attracted not only by military formations, but by the spectacular views as directly from the General Staff Building through a wide opening it was possible to see Neva, the Spit with the Rostral Columns and the domes of the Prince Vladimir Cathedral. The feminine part of the imperial family also showed some interest and from a balcony above the Saltykovsky entrance "observed how their husbands, sons and brothers participated in military exercises in front of the palace. In the summer, a green tent hung above the balcony to protect the public against rain and the sun" (Zimin, 2012).

1827 was a landmark as Nicholas I took an entirely new approach to the St. Petersburg architecture. By order of the emperor, on the western facade of the Winter Palace, "chamber" balconies were constructed in front of the closet of the imperial family. The purpose of this decision was exclusively pragmatic: the balconies made it possible to sit in fresh air and take a glance at beautiful urban panoramas. Their possible impact on the imposing appearance and the architectural image of

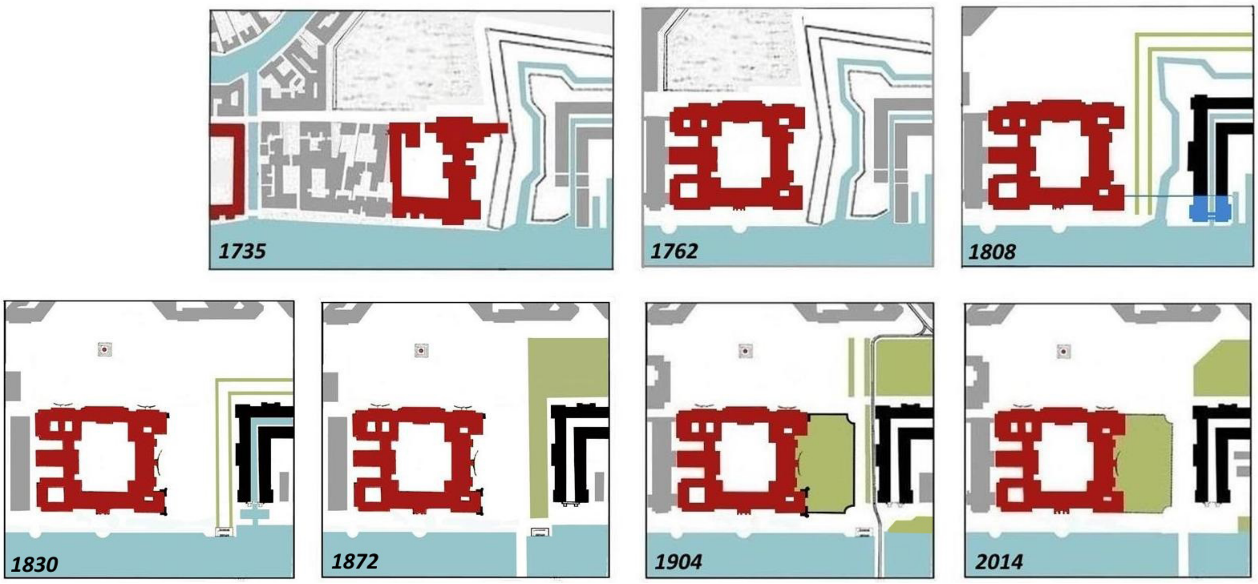

Figure 2. Evolution of buildings in the area between the Admiralty and the Winter Palace.

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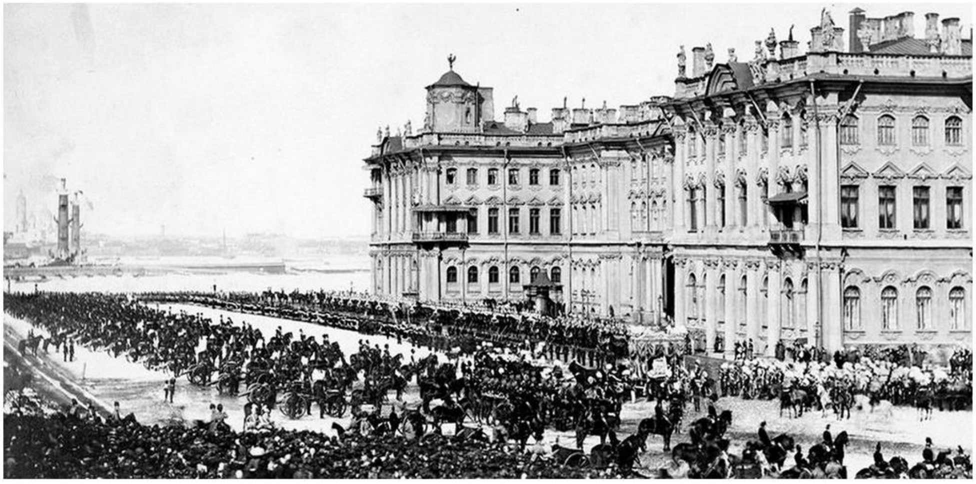

Figure 3. Above: a view of the Razvodnaya ground space in the middle of the 19th century, below: a view of the same space in the beginning of the 20th century.

the building was not considered at all. It is noted that the emperor thought only about the cost of the structure, and he did not take any interest in the architectural aspects ("Both balconies in a "cheap" option were worth 13,600 rubles. At first, Nicholas I was impressed with this figure... However, later, when he got used to the declared amount, the emperor allowed the construction of the balconies") (Zimin, 2012). The balconies that appeared on the facade of the Baroque structure looked weird (especially because they were decorated with textile canopies and shades). But they caught fancy of the residents of the Winter Palace, which is why they were renewed after the fire of 1837. Alien cover pieces disfigured the composition of the Rastrelli's facade for almost a century. The "illegal" structures were dismantled as late as in the 1920s.

One cannot but agree with a critical opinion on his role in the St. Petersburg architecture: "His reign was a turning point in the history of architectural and city-planning activities of the country... It is fair to say that from the first days of his rule, Emperor Nicholas maintained (and in many cases was the initiator of) the initiatives that actually meant rejection of the basic, fundamental principles of the architectural and city-planning policy that had been laid in the first quarter of the 18th century" (Kirichenko, 2010). However, it is obvious that the limitations made by Nicholas I in 1844 had a very positive impact on development of city landscapes. His order established the limit of height of 11 sazhens (23.47 m) for all residential buildings built in St. Petersburg: private residential houses could not be higher than the Winter Palace, although it was not directly mentioned in the order.

During the reign of Alexander II, the number of formal guard mounts reduced drastically, and city-planning changes in front of the Winter Palace were initiated. According to P.N. Stolpyansky, normally "the Admiralty square gave a very bad impression". He provided the following description of a contemporary: "Most of the day the Admiralty square is empty... it looks like a cut made inside the capital and filled with historic buildings, but not so vibrant as the center of the outstanding capital should be... Where are people?.. small groups on the steps of the Senate and Synod, some carriages, some pedestrians" (Stolpyansky, 1923). Easy merriment of public festivities, when carousels and ice-hills were built near the palace and noisy townfolk crowded the square, did not appeal to the habitants of the residence. It is not surprising that in 1872, the project of a garden in the place of the squares around the Admiralty, made by the Imperial

Russian Society of Gardening was "in general approved by the monarch" without any participation of architects. Alexander II "most graciously named the newly arranged garden after himself" (Stolpyansky, 1923). Soon, a dense green mass radically changed the landscape of the central part of the city. High overgrown trees destroyed the unity of the ensemble of the central squares. The space of the Palace Square was limited by the green of the Alexander Garden from the west, but it still had a visual contact with the Neva water area.

They were suppressed at the turn of the 20th century when the majority of the Razvodnaya ground was given to the "own garden of the Winter Palace" that was walled up with a high blind wall (Lavrov, Perov, 2015). As opposed to Nicholas I who located balconies on the facade of the palace without any aesthetic considerations, in this case, Nicholas II personally approved the project and sketches made in the Neo-Baroque style. In 1902, a fence was made along the perimeter of the garden.

It had a stylish effect: an open-work metal wrought lattice crowned a massive wall of slabs made of imported sandstone based on a granite foundation. The new garden with an area of almost 2 ha fenced with the 5 m high fence made a huge impact on the architectural image of the city center:

- the relationship between the Palace Square and the Neva space was disturbed and the visual connections with Vasilyevsky Island and the Petrograd Side were eliminated.
- the city lost a large public space, there was no more Razvodnaya ground where not only daily guard mountings, but also various public events were conducted.
- presence of sandstone in the structure of the fence surprisingly affected the coloristics of the whole central part of St. Petersburg. By order of Nicholas II, facades of all buildings of the imperial residence, buildings on the Palace Square and many other state-owned structures were repainted in the color of the "new fence of the Own Garden". Color gradations of elements of the order system and plastic decorations, characteristic of St. Petersburg, faded.

Monochromatic terracotta and brick-red colors contradicted the style of Baroque and Classicism buildings, suppressed the variety of their plastic compositions, but made the Russian capital look like European landscapes. "In European cities, sandstone was regarded as a regular decorative stone. It can be seen in Warsaw, Krakow, Poznan, Wroclav, Kielce, Berlin, Potsdam, Hamburg, Bremen, Munich, i.e. everywhere... Reichstag in Berlin. Its entire building is finished with sandstone" (Bulakh, 2009). The damage to the appearance of the city was obvious. The creative community recalled the former "beauty of light multi-shaded colors of St. Petersburg buildings" (Lukomsky, 1910).

They wistfully noted that a part of the Palace Embankment "from the Winter Palace to the Hermitage Theater would be magnificent if the painting of the building was not so depressing... it is disappointing", and the Palace Square "loses a lot because all buildings, aside from the Admiralty, are painted poorly" (Kurbatov, 1913). During the reign of Nicholas II, the Ministry of the Imperial Court, Budget Committee of the State Duma, Military Office, Ministry of Finance and Foreign Affairs repeatedly addressed the tsar regarding building repainting. They thought it was necessary to return the colors approved by Alexander I to the Winter Palace and the General Staff Building. Nicholas II rejected all those proposals (https://tsars-palaces.livejournal.com/15926.html).

Residence maintenance

From 1704 till 1918 (with small exceptions), the Cabinet of His/Her Imperial Majesty managed the personal money of the monarchs (so-called "cabinet" money) (http://knowledge.su/k/kabinet-ego-eyo-imperatorskogo-velichestva). A lot of matters related to development and functioning of the residences were solved by this office. Initially, the residence in St. Petersburg was quite small, and some of the maintenance functions were localized in direct neighborhood with the imperial family's closets. An orchard, a hennery and fish ponds supplying fresh products to the imperial table were built near the manor of practical Catherine the Great ("Golden Mansion") [43]. However, as early as at the initial stage of the establishment of the residential part of the residence, the Nourishing Palace (a multifunctional base) was constructed. A place near the Summer Palace of Peter the Great, on the opposite bank of Fontanka was allocated for it. Food stores, laundries, and residential houses for the staff were located there (Korentsvit, 2015). The Stable Yard — the center of transportation — developed nearby, on the Fontanka bank.

Many services ensuring the comfort of the imperial family, their relatives and the court were located at the imperial residences or nearby.

Under the project by F.B. Rastrelli, a show ring ("a show ring on the meadow") was built in 1732. In 1732–1735, the third Winter Palace was built. There, aside from residential and ceremonial rooms, there was a gallery, a theater, a large chapel, numerous stairs, service and guard rooms, as well as rooms of the court chancellory. This was not enough, and the palace was rebuilt right after. Technical buildings, sheds and stables were constructed on the meadow side (https://ria.ru/culture/20090627/175487226.html).

Medical facilities for the royal family

Before Nicholas II, no emperor or empress had ever been to a hospital. They were treated at home, and women of the royal family gave birth also at home. Under the reign of Alexander III, only court medical staff on duty was present in the Winter Palace.

Five physicians in ordinary were hired to the Winter Palace as late as in the end of 1895 when Nicholas II gave back the status of the main imperial residence to the Winter Palace (Zimin, 2012). During the reign of Nicholas II, specialized medical centers for the imperial family members were built "in the walking vicinity" of the Winter Palace:

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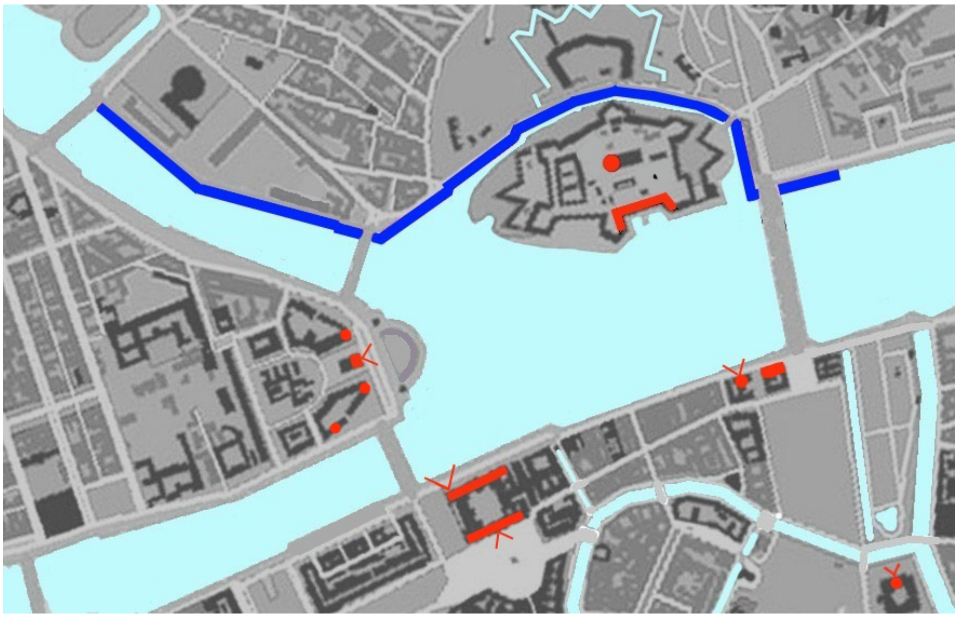

Figure 4. Prospective observation platforms in the area of the imperial residence in the center of St. Petersburg. Platforms on roofs are highlighted in red, and a pedestrian route along the water edge is highlighted in blue.

- in 1899–1904: on the Spit of Vasilyevsky Island, in the center of the Collegiate Square — the Imperial Obstetric and Gynaecological Institute headed by court obstetrician in ordinary D.O. Ott;

- in 1902–1906: on the Petrograd Side, in the Alexander Park — the K.Kh. Horn Orthopedic Institute. Doctor K.Kh. Horn was a physician and massage therapist of the empress, but he did not belong to group of the Court Medical Unit physicians. Nevertheless, the hospital was established as a part of the system for servicing the imperial family: the royal family contributed about 200,000 rubles for the construction, and about 800,000 rubles were given by the treasury. The empress showed her influence, and the land plot for the construction was provided for free, in an area where construction was forbidden (Zimin, Sokolov, 2015; http://www.nvspb.ru/stories/oni-schitalis-oshibkoy-56838/?version=print; https://www.zaks.ru/new/archive/view/72351-10).

Security system

The 18th century — the beginning of the 19th century was the time of palace revolutions where guards regiments were the active and decisive force, which is why armed guards were the essential part of the imperial residence. In the rear buildings of the Winter Palace, Elizabeth Petrovna accommodated the grenadier regiment that had helped her get the crown. The barracks for the 1st battalion of the Preobrazhensky regiment were built in the end of the 18th century at the corner of the Zimnyaya (Winter) Canal and Millionnaya Street, and later they were rebuilt in 1854–1857.

After the second half of the 19th century, terrorist bombers were the main danger for the royal family. In the first half of the century, Nicholas I "walked from 9 a.m. till 10 a.m. all alone and without any guards. The emperor, wearing a simple greatcoat, greeted acquaintances in a quite democratic way" (Zimin, 2012). After the death of Alexander II, his son decided not to risk, and Alexander III chose the Anichkov Palace as his residence, where he could walk around the garden fenced from the side of the square by a high blind wall (Lavrov, Perov, 2016). In 1896, based on that model, it was decided to create a safe zone in front of the rooms of the imperial family in the Winter Palace, and make a garden that would be a buffer between the palace and the Admiralty. The implementation of the project started. Special attention was paid to a protective fence, and the project for a safe fence for the garden was viewed and approved by the emperor himself (Zimin, 2012).

Transportation

It was important for Peter the Great to have daily communications with all parts of the city divided by water, which is why small harbors ensuring mooring of his personal small boat were made for him both in the winter and summer residences.

A slipway in the Winter Palace was intended for winter storage and repair of the boat. To ensure communications of the imperial residence with Moyka, the Zimnyaya (Winter) Canal was dug in 1718–1719. At the same time, the Neva embankment in front of the Winter House was moved several meters to the water area. It also was reinforced with stone, and a berth was constructed there. Probably, those were the first hydraulic works of such kind in St. Petersburg (even construction of a defense facility — the Galernaya Harbor — dates back to a later time). After the death of Peter the Great, his small boat was no longer needed, and the harbor at the Winter House was eliminated during the rule of Catherine I (Malinovsky, 2008).

In the 19th century, attention of the imperial families was attracted to voyages in the Gulf of Finland and farther. Accordingly, the size of imperial yachts increased, and their equipment became better:

- in 1826–1848, Nicholas I loved to go yachting in his yacht "Druzhba" with the displacement of 163 tons. In 1844, he got a present from England: a two-mast schooner-yacht with the displacement of 257 tons.

- In 1888, for Alexander III, a keel was laid down for the yacht "Polyarnaya Zvezda" at the Baltic Shipyard. It became a part of the Naval Guards. The ship with the displacement of 3750 tons was intended for distant voyages and equipped as a water residence.

The tsar's chambers reminded of luxurious palace rooms and included an entrance hall, a smoking room, a dining hall, two offices (for the emperor and the empress) and two sleeping rooms (for the emperor and the empress). In order to have fresh milk for the children, a room for the cowshed and a cabin for a dairymaid were provided.

- "Shtandart" of Nicholas II was a lot bigger (displacement of 5480 tons), and the imperial residence on board was far richer. Three blocks of cabins (having a living room, a sleeping room and a bathroom each) were provided for the emperor, the empress and the widowed empress.

There was a dining hall, a saloon, cabins for grand princes and princesses, cabins for royal children, cabins for Ladies of the Suite, Maids of the Bedchamber, the Chief Master of the Court, and rooms for servants (http://yachtinform.ru/yahty/imperatorskaya-nikolaya-ii.html). The imperial yachts were docked at the Kronstadt roadstead, and to ensure connection with the Winter Palace, steam boats were used. Respective berths were located along the Palace Embankment.

Nicholas II paid great attention to development of his personal stock of cars. In March 1917, 56 cars were in stock. Their role became greater when the residence was moved to Tsarskoe Selo. Cars were recommended for safety reasons. While in Crimea, the emperor preferred an open car with a canopy, and a limousine-type car was used to travel around the capital (https://tass.ru/spec/avto_imperatora).

In 1911, a garage for royal cars was built in St. Petersburg (4 years later than in the official residence — Tsarskoe Selo). It was located in the yard of the Winter Palace. Nearby, an underground gasoline storage "for 100 poods of gasoline" was built. The danger of a fire was not taken into account in that case (Zimin, 2012).

Conclusion

• 1703 – the 1750s: during those years, the capital of the empire was a small town representing a conglomerate of various settlements divided by undeveloped lands.

"St. Petersburg left by Peter the Great was a too poor and tiny town for us to consider it as something important" [55]. The poor city-planning situation does not interfere with active development of the residential complex. Places for winter and summer palaces, gardens and even hunting lands were found in the city.

• 1754 – the 1830s: the most fruitful stage of residence development, successful solutions to the task of its imposing appearance; widening the area of the winter residence due to the use of the Neva water area and squares around the Admiralty (the phenomenon of the Mikhailovsky Castle is beyond this strategic direction). The core of the city center formed. An outstanding result was achieved thanks to the targeted use of natural potential due to creative contribution of great architects and corresponding financing of projects ("Moscow was built in centuries, and St. Petersburg — in millions"). The goal of reaching the particular aesthetic parameters played the decisive role.

• the 1870s — 1917: evolution of the complex in the capital was aimed at solving more complicated pragmatic tasks related to safety, recreation and provision of medical services to the imperial family. The residence complex was enlarged due to utility facilities, and the spatial area of the Winter Palace was reduced.

New structures of the residence (the Own Garden, Ott's clinic, and Orthopedic Institute) deform the historical landscapes. A conflict between the residence and the city occurs due to the diverse views on the use of territorial resources of the central part of the city. The imminent change in the political system — the transformation of autocratic Russia into the Duma monarchy — showed (https://www.the-village.ru/village/weekend/read-books/233211-eva-berar).

The official residence of the Russian emperor was moved to the suburbs of St. Petersburg. It turned out that the model of a suburban royal residence created in Versailles in the 17th century met the requirements of the Russian monarch's family in the beginning of the 20th century (http://stadtgeschichtchen.de/artikel/stadtgeschichte/was-ist-eine-residenzstadt/).

• modern times. The facilities that were included in the imperial residence are currently the basis "of the original structures in Saint Petersburg's historic centre... testament to its outstanding universal value... integrated value as the historic urban landscape".

It is believed that "the city has preserved the authenticity of its chief components", which contributes to the original image of the city and attracts masses of townsfolk and tourists to the center. However, growing automobilization makes it difficult for people to optimistically perceive the unique landscape potential of the city center. Pedestrians are forced away from the embankments by dense traffic flows.

The unique panoramas created during the past centuries cannot be presented in full. We should turn to the lessons from the past to solve the problem: the family of Nicholas II, who could not walk along the Neva embankments freely (although for other reasons), used galleries on the roofs of the residence with great pleasure. Nowadays, terraces overlooking the historical center are arranged on the roofs of museums in Paris and Florence. In St. Petersburg, this experience has been used by the Hermitage and Peter and Paul Fortress where wooden footbridges are installed above the roofs. The expected reconstruction of the Stock

Exchange gives great opportunities: the unique landscapes that can be viewed from the large flat roof rising almost 30 m above the Neva water area can become

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accessible to people. The view of the historical center from the water level will be ensured by pedestrian routes that can be laid along the embankments on the northern bank of Neva.

Unfortunately, the project "Embankment of Europe" neglected the landscape potential of this place and, therefore, did not provide for a relevant platform neither on the roofs of the erected buildings nor near their footing.

It is obvious that the task of such prospective stage would be restoration of great views on open spaces in the Winter Palace area and provision of the opportunity to view the main facade of the Admiralty. This can be achieved upon reconstruction of green landscapes of the Alexander Garden... The process will take many years, but St. Petersburg is still a young city, and it has a great story ahead of it.

References

Bakhareva, N.Yu., Kalnitskaya, E.Ya., Puchkov, V.V. (2003). *Mikhailovsky Castle: pages of the monument biography in documents and literature.* Moscow: Rossiysky Arkhiv.

Bass, V. (2009). *Saint Petersburg Neoclassical architecture of the 1900s–1910s in the context of competitions: the word and the shape.* Saint Petersburg: EUSP Press.

Bulakh, A.G. (2009). *Stone decorations of Saint Petersburg*. Moscow: Tsentrpoligraf.

Bunin, A.V., Savarenskaya, T.F. (2017). *History of city-planning art. Streets and embankments*. Available at: http://townevolution.ru/books/item/f00/s00/z0000021/st039.shtml (accessed on: 12.01.2019).

Dubyago, T.B. (1963). *Russian regular gardens and parks.* Leningrad: Gosstroyizdat.

Georgi, J.G. (1790). *Russian imperial residence in Saint Petersburg and peculiarities of the area.* Saint Petersburg: Verlag C.W. Müller, XVI.

Georgi, J.G. (2001). *Description of the Russian imperial capital city of Saint Petersburg and the memorable sites in its suburbs.* B.m.: Adamant Media Corporation.

Grabar, I.E. (1910). *History of the Russian art.* Moscow: J. Knebel Publishing House.

Frolov, A.I. (2005). *Saint Petersburg from A to Z. Rivers, canals, islands, bridges, embankments.* Saint Petersburg: Glagol.

Ivanova, V.P. (1981). *Gardens and parks of Leningrad.* Moscow: Lenizdat.

Kirichenko, E.I. (1997a). *Moscow imperial palaces as a problem of history of art.* Moscow: Moscow Architecture Preservation Society (MAPS).

Kirichenko, E.I. (1997b). *Concerning two concepts of the imperial residence: Winter Palace in St. Petersburg after the fire of 1837 and Grand Kremlin Palace in Moscow*. Moscow: Moscow Architecture Preservation Society (MAPS).

Kirichenko, E.I. (ed.) (2010). *Town planning in Russia of the mid 19th – early 20th centuries. Capitals and provinces*, volume 3. Moscow: Progress-Traditsiya.

Korentsvit, V. (2015). *Summer Garden of Peter the Great. A story about the past and the present.* Moscow: Tsentrpoligraf.

Kurbatov, V.Ya. (1913). *Petersburg: Artistic and historical sketch and review of the artistic wealth of the capital.* Saint Petersburg: Community of St. Eugenia (Partnership of R. Golike and A. Vilborg).

Lavrov, L., Perov, F. (2015). The landscape development of Saint Petersburg (1853–2003). P*roceeding of the Institution of Civil Engineers — Urban Design and Planning*, 168 (5), pp. 259–266. DOI: 10.1680/udap.15.00016.

Lavrov, L., Perov, F. (2016). Appropriate architecture. Capriccio on the Spit of Vasilyevsky Island. *SPbSU Bulletin*, 15 (4), pp. 52–86.

Levontina, I.B. (1995). *New explanatory dictionary of synonyms of the Russian language. Institute of Russian language. Russian Dictionaries*. Moscow: Russian culture languages.

Lisovsky, V.G. (2004). *Architecture of Saint Petersburg. Three centuries of history.* Saint Petersburg: AO Slaviya.

Lukomsky, G.K. (1910). *Architectural chronicle*, No. 11. Saint Petersburg: Apollon.

Malinovsky, K.V. (2008). *After the Death of Peter the Great. Saint Petersburg in the 18th century.* Saint Petersburg: Kriga.

Petrova, O.V. (2006). *Gatchina in 1783–1855: a residence town in the context of Russian city-planning culture.* PhD in Art History. Moscow: Russian State University for the Humanities.

Sashonko, V.N. (1982). *The Admiralty*. Leningrad: Lenizdat.

Shuysky, V.K. (1989). *Andreyan Zakharov*. Leningrad: Lenizdat.

Sindalovsky, N.A. (2012). *Legends of Saint Petersburg parks and gardens*. Saint Petersburg: Tcentrpoligraf.

Stolpyansky, P.N. (1923). *Old Petersburg: Admiralty Island. Labourers Garden*. Moscow; Petrograd: GIZ.

Zimin, I.V. (2012). *Winter Palace. People and walls. History of the imperial residence, 1762–1917.* Moscow: Tsentrpoligraf.

Zimin, I., Sokolov, A. (2015). *Charitable activities of the House of Romanov: motivation, traditions and legal forms.* Saint Petersburg: Tcentrpoligraf.

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ANALYSIS OF STRENGTH CHARACTERISTICS IN RAILROAD DOWELS PRODUCED BY VARIOUS MANUFACTURERS

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Abstract

The article describes operating conditions of the railroad dowel used in ZhBR 65 resilient rail fasteners. Requirements for railroad dowel tests in terms of their expediency, possibility to perform such tests and conformity with the actual operating conditions are analyzed. The initiative of the authors, arisen during an analysis of regulatory documents, served as a basis for the studies. Stresses in a dowel and its safety factor in operation and tests were determined analytically by the finite element method, using the APM FEM library, the system of strength analysis for KOMPAS-3D, certified within the GOST-R system.

Railroad dowels manufactured by OOO NTT, ZAO Polimer ZAO and Vossloh Fastening Systems GmbH were used as study objects. For the purposes of simulation, 3D models of the corresponding dowels and their mating parts (sleeper, railroad screw, tension clamp, etc.) were built. According to the studies, in tensile tests of dowels, conducted according to Clause 4.6 of Specifications TsP 369 TU-7, stresses of 85...100 MPa occur in the bodies of all dowels under consideration, which considerably exceed stresses appearing in dowels during operation, and the nature and distribution of such stresses do not correspond to those of operating stresses, the maximum value of which does not exceed 10 MPa.

The analysis of stresses arising in sleepers with dowels by the manufacturers under consideration has shown that their limit value is 75 MPa. Besides, in sleepers with dowels by OOO NTT and Vossloh Fastening Systems GmbH, the maximum stresses are in the sleeper body, which allows for their redistribution and prevents dowel pulling-out from a sleeper. Sleepers with dowels made by ZAO Polimer have maximum stresses in the upper face of a sleeper coaxially with the dowel axis, which significantly increases the probability of dowel pulling-out in case of extreme loads.

Keywords

Railroad dowel, rail fastener, track structure, internal stresses, yield strength, ultimate strength, safety factor.

Introduction

A railway track, the structure and maintenance of which are specified in a number of regulatory documents, represents the basic element of the railroad transport infrastructure (Ministry of Railways, 2001, 2003; Russian Railways, 2013). Rail fasteners play an important role in reliability of the track structure (Karpushchenko, 2007; Karpushchenko, Antonov, 2003; Kuznetsov, Eremushkin, 2006), which is why their structure (as the structure of their components) is constantly improved and tested.

Since the beginning of the 2000s, in the railroad sector of Russia, resilient rail fasteners have been mainly used as they provide immobility of rail bars and reliability of their fastening during operation due to firmer contact between a rail and a foundation, ensured by a tension clamp, regardless of the ambient temperature.

A general view of a rail fastener is given in Figure 1.

As follows from this figure, track 1 is laid on sleeper 2 over rail pad 7 and fastened using dowel 8 and screw 3. In transverse direction, the track is fastened by side

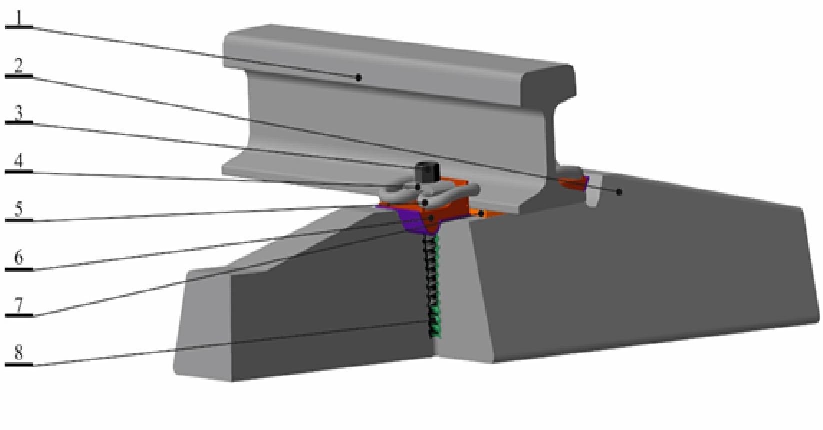

Figure 1. A general view of a resilient screw/dowel rail fastener
1 — track, 2 — sleeper, 3 — screw, 4 — brace, 5 — tension clamp, 6 — side stop, 7 — rail pad, 8 — railroad dowel.

stops 6, and vertically — by tension clamp 5. The vertical pressing force of the track, as well as the load on the dowel and screw are determined only by the deformation force of the tension clamp (Russian Railways, 2013). In Russian Railways (2016), dowels manufactured by OOO NTT (Russian Railways, 2016; Nikitin et al., 2013, 2014], dowels manufactured by ZAO Polimer (VNIIZhT JSC, 2011; Borodin et al., 2013; Akimov et al., 2008; Akimov, 2006, 2009a, 2009b, 2011, 2012) and dowels manufactured by Vossloh Fastening Systems GmbH (2010) are used.

To manufacture dowels, OOO NTT uses its own polymer compound (Nikitin et al., 2009; Nikitina, Nikitin, 2013, 2015; Nikitina, Kosobudsky, 2016; Nikitina et al., 2013) based on polypropylene, ZAO Polimer uses Armlen PP-SV 10-2T, which is glass-filled polypropylene, and Vossloh Fastening Systems GmbH uses polyamide PA 6. Basic physical and mechanical properties of the materials are given in Table 1.

Table 1. Physical and mechanical properties of dowel materials.

Indicator	PP-SV 10-2T	Polyamide PA 6
Yield strength [MPa]	85	65
Normal modulus of elasticity [MPa]	2,800	2,200
Poisson's ratio	0.35	0.3
Density [kg/m3]	990	1,135
Thermal coefficient of linear expansion [1/°C]	0.000012	0.000012
Thermal conductivity [W/(m·°C)]	1	1
Compression strength [MPa]	60	410
Tensile fatigue limit [MPa]	56	65
Torsional fatigue limit [MPa]	139	139

Calculation of stresses arising in dowels in tensile tests.

Railroad dowels manufactured by OOO NTT (Figure 2a), ZAO Polimer (Figure 2b) and Vossloh Fastening Systems GmbH (Figure 2c) were used as the study objects. The subject of the study included strength characteristics of dowels made by different manufacturers, dowel structure impact on strength characteristics of sleepers, and justifiability of the requirements (Russian Railways, 2016). for the dowels of rail fasteners, which is conditioned both by the opinion of the manufacturers considering some requirements to be redundant and the issues brought up by the scientific community (Russian Railways, 2017; Dydyshko, 2009).

To model stresses and deformations occurring in dowels made by different manufacturers, as well as the safety factor during tests conducted according to Clause 4.6 (Russian Railways, 2016) (tensile tests), 3D models of the dowels cut short in the bottom, made as per recommendations (Alexandrova, Zaytseva, 2012, 2013; Bolshakov et al., 2010), were used. The head of the screw turned into the dowel from the bottom was rigidly fixed at its face surfaces, and the force of 5 kN was applied to the "lower" face surface of the head of the "upper" dowel (Figure 3).

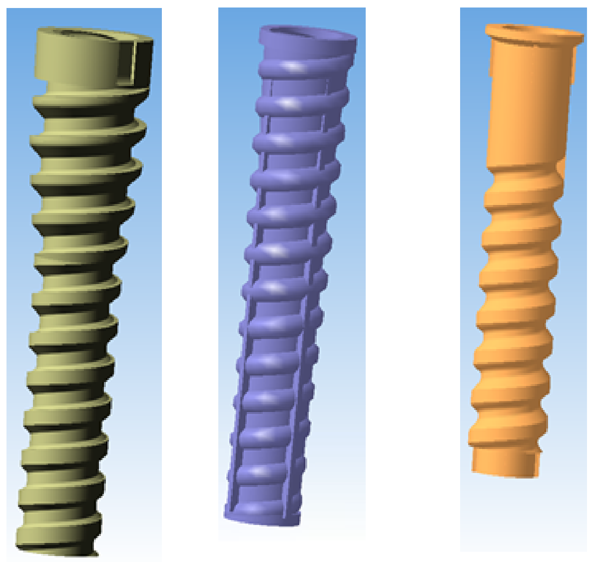

Figure 2. Appearance of dowels made by different manufacturers:
a — OOO NTT, b – ZAO Polimer, c – Vossloh Fastening Systems GmbH.

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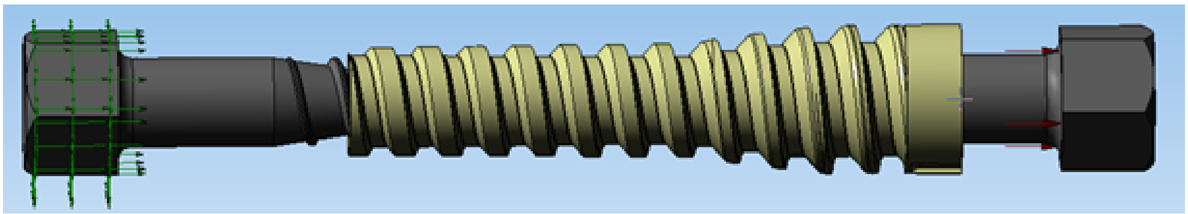
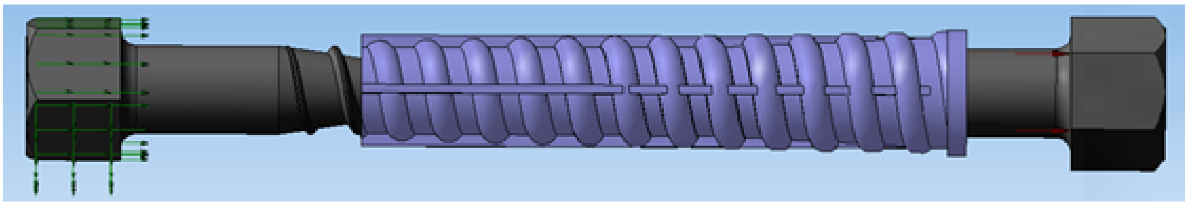
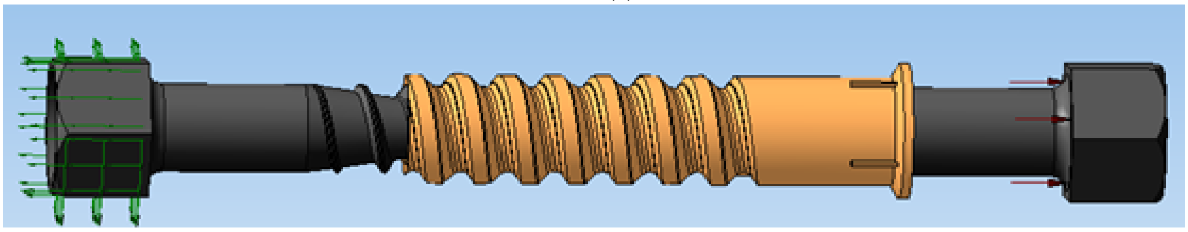


(a)



(b)



(c)

Figure 3. 3D models with the dowels, made by different manufacturers, cut short in the lower part
a — OOO NTT, b – ZAO Polimer, c – Vossloh Fastening Systems GmbH.

To verify conformity of the model with the requirements (State Committee of the USSR for Standards, 1980), tensile tests were conducted.

During finite element (FE) division, a non-regular grid, 4-node tetrahedra with the element side length of 3 mm, fine grid coefficient 5 and coarse grid coefficient 1.5, were used.

The results of the division are presented in Table 2.

Calculation of stresses in the dowels during tensile tests (according to the requirements (Russian Railways, 2016) has shown the following:

1. The maximum stresses [σmax] in all dowels are 85…100 MPa (Figure 4).

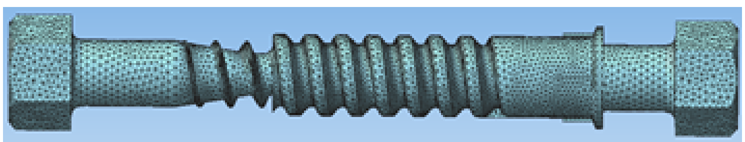
2. All dowels have the maximum stresses on a relatively small area.

3. The nature of stress distribution is approximately the same in all dowels.

To find out if the strength is sufficient, the safety factor was calculated. The corresponding results are given in Figure 5. In the weakest cross-sections, the minimum values of the safety factor were the following: 3.64 for the dowels made by Vossloh Fastening Systems GmbH, 0.58 for the dowels made by OOO NTT, and 0.74 for the dowels made by ZAO Polimer. Thus, only the dowels manufactured by Vossloh Fastening Systems GmbH can stand the tests.

However, it should be noted that during tests, stresses in all dowels are close in their values, and positive results obtained for the dowels made by Vossloh Fastening

Table 2. Division results.

Manufacturer	Number of FEs	Division result
OOO NTT	639,504	
ZAO Polimer	1,190,459	
Vossloh Fas-tening Systems GmbH	172,168	

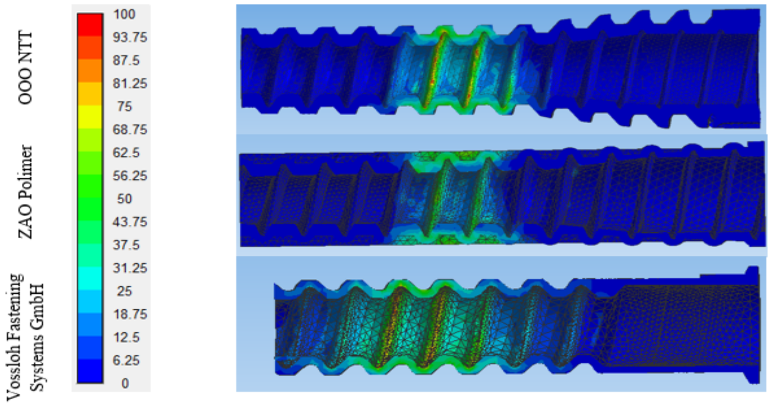


Figure 4. Distribution of stresses in the bodies of dowels, made by different manufacturers, during tensile tests, MPa.

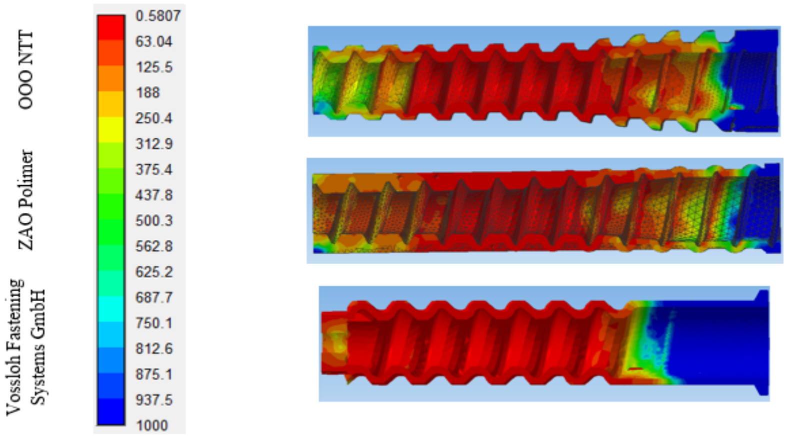


Figure 5. Safety factor distribution maps for stresses in the bodies of dowels, made by different manufacturers, during tensile tests.

Systems GmbH are determined by the material properties only, and not by the dowel structure.

In order to confirm (or deny) this statement, we have peformed similar calculations for the dowels made by OOO NTT and ZAP Polimer ZAO of polyamide, and the dowels made by Vossloh Fastening Systems GmbH of armlen. Under those conditions, the calculation results with regard to the safety factor distribution map were (minimum values) 2.6, 4.8 and 0.58, respectively. The summary results of studying the strength characteristics of all dowels are given in Table 3.

Table 3. Minimum safety factor values of dowels made by different manufacturers (in the weakest cross-sections).

Manufacturer	Dowel material	
	Armlen	Polyamide
OOO NTT	0.58	2.6
ZAO Polimer	0.74	4.8
Vossloh Fastening Systems GmbH	0.58	3.64

As follows from Table 3, the safety factors of dowels made by different manufacturers do not vary significantly, which means that their structures are of equal strength.

Intermediate conclusions:

1. The values of stresses occurring in the bodies of dowels under consideration in tensile tests are approximately the same.

2. The operating part of a dowel made according to the corresponding requirements (Karpushchenko, 2007) has higher stresses in the operating area.

3. A higher safety factor of a dowel made according to the corresponding requirements (Karpushchenko, 2007) (Vossloh) is determined only by the use of stronger and more expensive materials. When a dowel is made of armlen, as dowels made according to the corresponding Specifications and Instructions (Ministry of Railways, 2003; Russian Railways 2013), its strength characteristics do not exceed similar characteristics of dowels made according to such Specifications and Instructions (Ministry of Railways, 2003; Russian Railways 2013).

Analysis of stresses and strength characteristics of dowels in operation

In order to evaluate justifiability of the 5 kN load applied to a dowel in tensile tests, let us determine stresses and safety factors in the body of a dowel while in operation.

Analytical 3D models are given in Figure 6.

With account for studies of Karpushchenko and Antonov (Karpushchenko, Antonov, 2003), the maximum axial force on a screw during installation is 4.1 kN, therefore, performing calculations, we will consider the load of 5 kN (exceeding he standard value by 25%) to be justified. However, it should be taken into account that sleeper load conditions differ from operating conditions significantly. As we do not consider the sleeper strength in this part of the study, in order to reduce the machining

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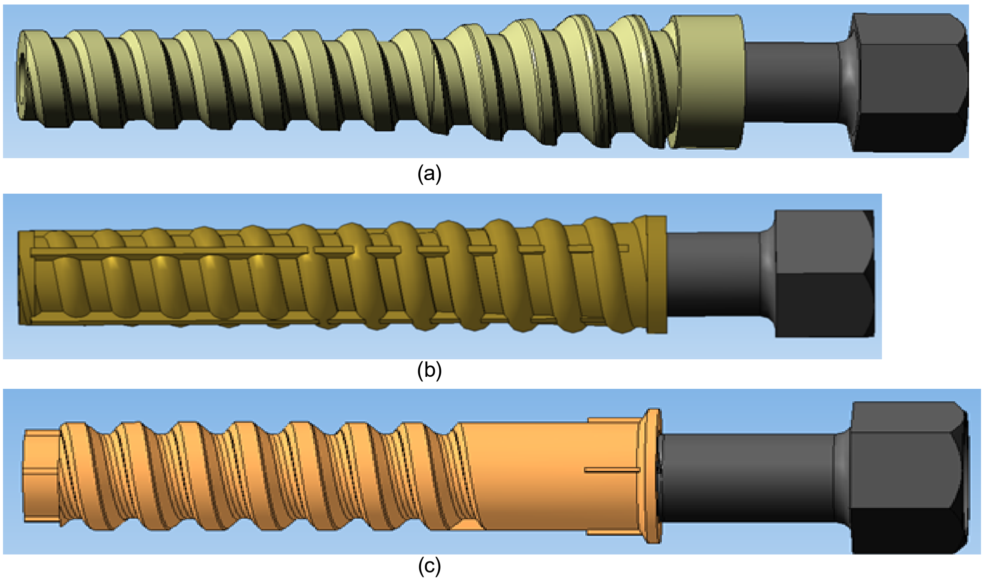

Figure 6. 3D models of dowels made by different manufacturers
a — OOO NTT, b – ZAO Polimer, c – Vossloh Fastening Systems GmbH.

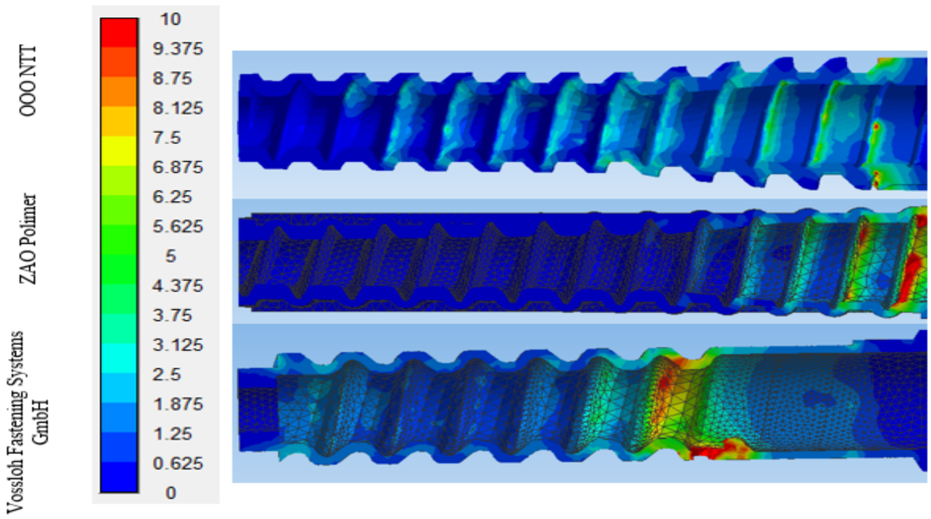

Figure 7. Distribution of stresses in the bodies of dowels, made by different manufacturers, at the operating load in a sleeper, MPa.

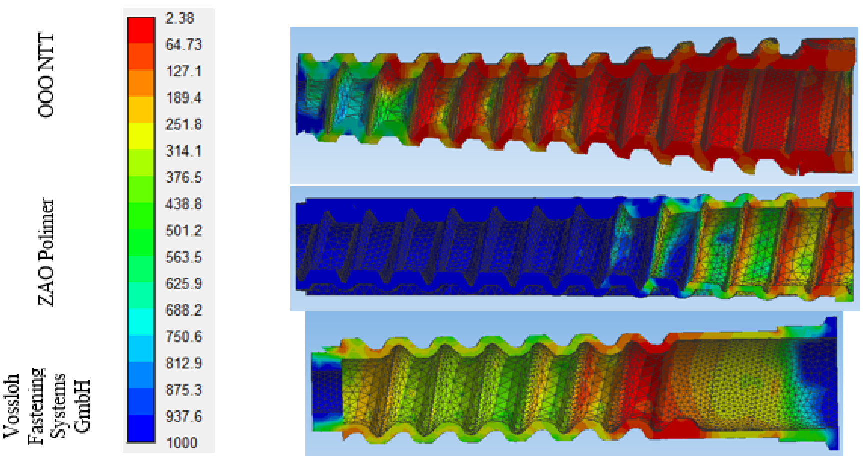

Figure 8. Safety factor distribution in the bodies of dowels, made by different manufacturers, at the operating load in a sleeper.

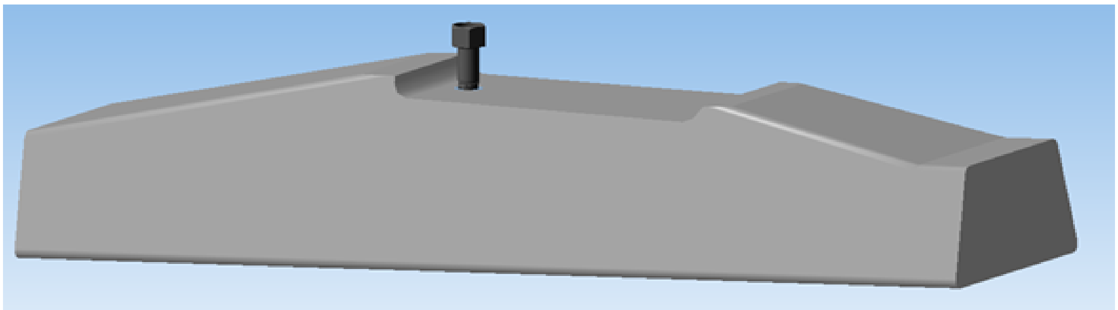

Figure 9. 3D model of an assembled half-sleeper with a dowel and a screw.

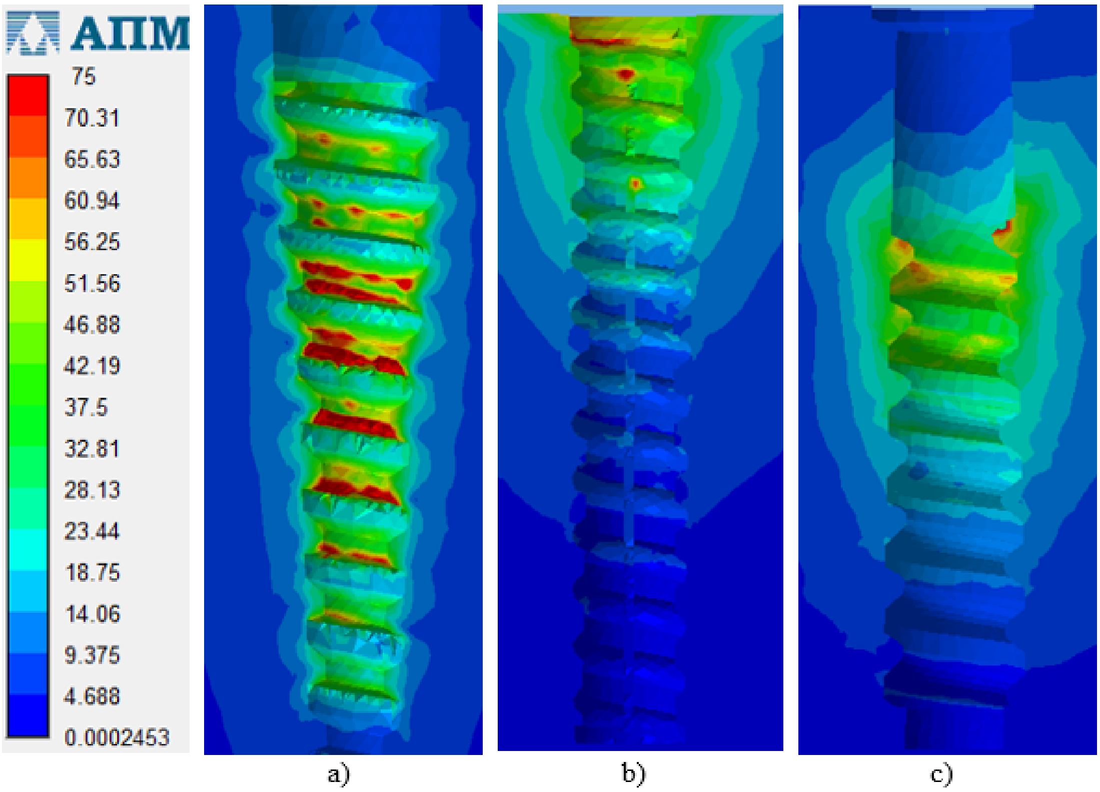

Figure 10. Distribution of stresses in cross-sections of sleepers, coaxial with the dowel axis, with dowels made by: a — OOO NTT, b — ZAO Polimer, c — Vossloh Fastening Systems GmbH (MPa).

time along the outer surface of dowels, we will set normal fastening, which corresponds to a dowel embedded in concrete, and determine stresses occurring in the body of a dowel as well as safety factors.

The calculation results are given in Figure 7 and Figure 8.

As follows from Figure 7, stresses occurring in dowels during operation are significantly lower than those in tensile tests conducted according to the Regulations (Ministry of Railways, 2001). In particular, the maximum stress in the body of the dowel made by OOO NTT is 5 MPa, by ZAO Polimer — 6 MPa, by Vossloh Fastening Systems GmbH — 8 MPa (in fragments).

Besides, the nature and zoning of stress distribution shall be paid attention to as they show that tests conducted according to Clause 4.6 (Ministry of Railways, 2001) have nothing in common with the actual operating conditions in terms of the stress nature and value.

The minimum safety factor value (Figure 8) for the dowel made by OOO NTT is 9.159, by ZAO Polimer — 5.54, by Vossloh Fastening Systems GmbH — 11.53. Therefore, strength characteristics of all dowels are beyond question and have significant safety factor in operation.

Intermediate conclusions:

1. The maximum values of stresses in all dowels during operation do not exceed 10 MPa, which is substantially less than those during tests conducted according to Clause 4.6 (Ministry of Railways, 2001).

2. The safety factor of dowels made according to the particular requirements (Ministry of Railways, 2003; Russian Railways, 2013; Karpushchenko, 2007) is significantly higher than 3, which means that their strength characteristics correspond to the operating conditions with a significant safety factor.

General analysis of dowel structure impact on strength characteristics of sleepers

As resistance of reinforced concrete sleepers to dowel pulling-out with regard to sleepers with screw/dowel rail fasteners has not been studied yet (Omarova,

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2010), we will analyze dowel structure impact on strength characteristics of sleepers. It should be noted that in order to determine strength characteristics of a screw/dowel rail fastener, corresponding tests are conducted according to Clause 4.9 (Russian Railways, 2016).

Using the method described in Section 1, we determined stresses occurring in sleepers with dowels of different structures at tests conducted according to Clause 4.9 (Russian Railways, 2016). For that purpose, 3D models of half-sleepers, used in tests, with dowels and screws were built (Figure 9).

According to the calculation results, stresses occurring in the bodies of dowels during such tests reach 70 MPa, which exceeds manifold the value of stresses occurring in dowels during operation.

The analysis of stresses (Figure 10) occurring in sleepers has shown that their maximum value reaches 75 MPa. In sleepers with dowels made by OOO NTT and Vossloh Fastening Systems GmbH, the maximum stresses are in the sleeper body, which makes their redistribution possible and prevents dowel pulling-out from the sleeper.

Sleepers with dowels made by ZAO Polimer have maximum stresses in the upper face of a sleeper coaxially with the dowel axis, which significantly increases the probability of dowel pulling-out in case of extreme loads.

Conclusions

1. According to the calculations, in tensile tests of dowels conducted according to Clause 4.6 (Russian Railways, 2016), stresses of 85...100 MPa occur in the bodies of all dowels under consideration, which considerablt exceed stresses appearing in dowels during operation, and the nature and distribution of such stresses do not correspond to those of operating stresses.

2. The maximum values of stresses in all dowels during operation do not exceed 10 MPa, which is substantially less than those during tests conducted according to Clause 4.6 (Russian Railways, 2016). The safety factor of dowels made according to the particular requirements (Russian Railways, 2017; VNIIZhT JSC (Railway Research Institute), 2011; Vossloh Fastening Systems GmbH, 2010) is significantly higher than 3, which means that their strength characteristics correspond to the operating conditions with a significant safety factor.

3. During strength tests conducted according to 4.9 (Russian Railways, 2016), stresses occur in dowels, the nature of which corresponds to that of the operating stresses, and the value of which reaches 75 MPa, which exceeds manifold the value of stresses occurring in dowels during operation, which is why it is expedient to omit tensile tests conducted according to Clause 4.6 (Russian Railways, 2016) since they are redundant and do not reflect the actual conditions of dowel operation.

4. The analysis of stresses arising in sleepers with dowels by the manufacturers under consideration has shown that their limit value is 75 MPa. Besides, in sleepers with dowels by OOO NTT and Vossloh Fastening Systems GmbH, the maximum stresses are in the sleeper body, which allows for their redistribution and prevents dowel pulling-out from a sleeper.

Sleepers with dowels made by ZAO Polimer have maximum stresses in the upper face of a sleeper coaxially with the dowel axis, which significantly increases the probability of dowel pulling-out in case of extreme loads.

References

Akimov, V.P. (2006). *Dowel fixing rail fastening*. Patent RU56899U1.

Akimov, V.P. (2009a). *Dowel fastening rail fastening assembly.* Patent RU89532U1.

Akimov, V.P. (2009b). *Dowel fastening rail fastening assembly.* Patent RU89533U1.

Akimov, V.P. (2011). *Fixing rail fastening assembly and used in the dowel and a screw*. Patent RU104188U1.

Akimov, V.P. (2012). *Dowel rail fastening*. Patent RU113743U1.

Akimov, V.P., Krysanov, L.G., Serebrennikov, V.V., Ressina, N.V. (2008). *Dowel fastening rail fastening assembly.* Patent RU71662U1.

Alexandrova, V.V., Zaytseva, A.A. (2012). 3D-technologies and cognition programming. *Information-measuring and Control Systems*, 10 (5), pp. 61–65.

Alexandrova, V.V., Zaytseva, A.A. (2013). 3D modeling and 3D prototyping of complex space forms in the technology of cognitive programming. *SPIIRAS Proceedings*, 4 (27), pp. 81–92.

Bolshakov, V., Bochkov, A., Sergeev, A. (2010). *3D modeling in AUTOCAD, KOMPAS-3D, SOLIDWORKS, INVENTOR, T-FLEX: Training course*. Saint Petersburg: Piter.

Borodin, S.P., Akimov, V.P., Ressina, N.V. (2013). *Dowel and method of sleeper repair.* Patent RU2482236C1.

Dydyshko, P.I. (2009). Analysis of current normative documents on design and maintenance of permanent way and roadbed. *Vestnik of the Railway Research Institute*, 6, pp. 15–21.

Karpushchenko, N.I. (2007). Issues and prospects of track structure improvement. *The Siberian Transport University Bulletin*, 16, pp. 42–62.

Karpushchenko, N.I., Antonov, N.I. (2003). *Improvement of rail fasteners.* Novosibirsk: Publishing House of the Siberian Transport University.

Kuznetsov, V.V., Eremushkin, A.A. (2006). Testing of rail fasteners continues. *Railway Track and Facilities*, 5, pp. 14–17.

Ministry of Railways (2001). *Regulations on track facilities in the Russian Federation*. Moscow: Ministry of Railways, p.79.

Ministry of Railways (2003). *Specifications for repair and preventive and predictive maintenance of tracks. TsPT-53.* Moscow: Ministry of Railways, p. 150.

Nikitin, D.A., Krivosheev, A.V., Kuznetsova, K.A. (2014). *Dowel the mounting rail fastening assembly.* Patent RU144345U1.

Nikitin, D.A., Vasilyev, A.Ye., Nikitina, L.V. (2009). *Polypropylene composition.* Patent RU2353635C1.

Nikitin, D.A., Vasilyev, A.Ye., Krivosheev, A.V., Kuznetsov, G.A. (2013). *Dowel fastening rail fastening assembly.* Patent RU127755U1.

Nikitina, L.V., Kosobudsky, I.D., Ushakov, N.M. (2013). Systems based on thermoplastic polymer with improved thermoplastic properties. In: *Proceedings of the 10th International Scientific and Practical Conference with Virtual Participation "Scholarly Discussion: Problems of Mathematics, Physics, Chemistry and Biology",* 10, pp. 66–70

Nikitina, L.V., Kosobudsky, I.D. (2016). Modification thermoplastic polymer nanoparticles of silica and properties of obtained composites. In: *Proceedings of the International Conference "Prospective Polymeric Composite Materials. Alternative Technologies. Processing. Application. Environment" ("Kompozit-2016"),* pp. 232–234.

Nikitina, L.V., Nikitin, D.A. (2013). Polypropylene modification with nano-sized silicon dioxide in order to change its mechanical properties. *Science Review,* 10, pp. 116–123.

Nikitina, L.V., Nikitin, D.A. (2015). Physical-mechanical properties of a composite polymeric material based on polypropylene doped with titanium dioxide nanoparticles. *Scientific Thought,* 3, pp. 359–363.

Omarova, G.A. (2010). Experimental studies of resistance to anchor and dowel pulling-out from reinforced concrete sleepers. In: *Proceedings of the 6th International Scientific and Practical Conference "Recent Scientific Advances — 2010"*, 19, pp. 41–46.

Russian Railways (2013). *Instructions for assembly, installation and operation of a track with a ZhBR-65PSh rail fastener with a polymeric rail pad on reinforced concrete sleepers.* Available at: http://zddoc.ru/normdoc/instruktsiya-1815r-ob-utverzhdenii-i-vvedenii-v-deystvie-instruktsii-na-sborku-ukladku-i-ekspluatatsiyu-puti-s-razlichnyimi-modifikatsiyami-relsovogo-skrepleniya-zhbr-na-zhelezobetonnyih-shpalah/. (accessed on: 14.01.2019).

Russian Railways (2016). *Dowel. Specifications TsP 369 TU-7.* Available at: http://zakupki.gov.ru/223/purchase/public/download/download.html?id=40535008. (accessed on: 12.02.2019).

Russian Railways (2017).*Plastic dowel for reinforced concrete sleepers (ShZ-D type) with ZhBR-65Sh screw/dowel rail fasteners. Specifications TU 2291-001-82660849-2012*. Moscow: Russian Railways.

State Committee of the USSR for Standards (1980). *State Standard GOST 11262-80. Plastics. Tensile test method.* Moscow.

VNIIZhT JSC (Railway Research Institute) (2011). *Modernized plastic dowel for reinforced concrete sleepers (ShZ-D type) withr ZhBR-65Sh screw/dowel rail fasteners. Specifications TU 2291-207-01.00.000.* Available at: zakupki.gov.ru/223/purchase/public/download/download.html?id=40194548. (accessed on: 11.01.2019).

Vossloh Fastening Systems GmbH (2010). *Plastic dowel Sdü 25. Specifications TU 01.1.3419-2010.* Available at: zakupki.gov.ru/223/purchase/public/download/download.html?id=32753536. (accessed on: 01.02.2019).

SELECTION OF THE TECHNOLOGICAL LINE STRUCTURE FOR THE BUILDING AGGREGATES PRODUCTION USING CENTRIFUGAL IMPACT CRUSHERS

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Abstract

The paper considers the problem of the organization of the technological line for the production of building aggregates with a given particle size distribution. The advantage of two-stage crushing schemes is shown, which makes it possible to ensure a change in the ratio of large aggregate fractions within fairly wide limits.

The experience of using centrifugal-impact crushers for the operation of the production of CJSC Ural-Omega at the final stage of crushing is summarized. It was demonstrated that the use of two centrifugal impact crushers at the final stage of crushing allows to obtain mixtures of significantly different types. A method for selecting the option of organizing the process line and crushing parameters is proposed.

Keywords

Crushing and grading complex, centrifugal crushers, particle-size distribution of structural filling aggregates.

Introduction

The designing of concrete and asphalt-and-concrete mixes constitutes a challenging scientific and engineering task, since the results of solving it determine the qualitative indicators and cost of the final product.

The quality of filling aggregates as well as the particle-size distribution thereof plays an important role in designing and production of concretes. Therefore, a competent selection of sand content in the mix of filling aggregates (ratio of sand weight to the sum of weights of sand and crushed stone) providing the maximum concrete mix placeability with minimum binder consumption, is an essential part of designing concrete.

The value of sand content can be expressed as a function of cement paste, for which purpose a corresponding graph (Figure 1) will be provided during work (Sukhodoeva, Babitsky, 2009). This graph shows that the increase of sand content in the mix of filling aggregates will bring about an increase of concrete mix plasticity with the same of cement paste volume. Thus, we can make a conclusion that the particle-size distribution of filling aggregates directly influences the concrete mix plasticity and placeability.

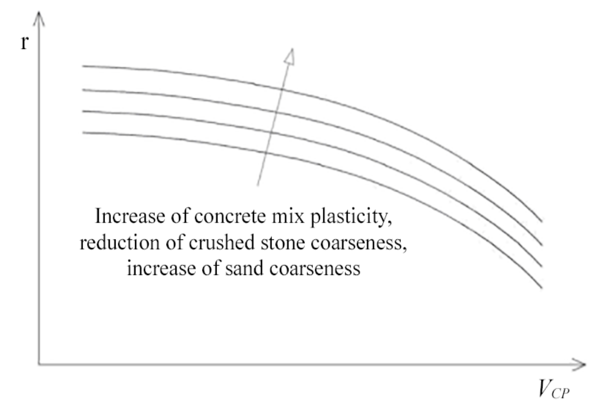

Figure 1. Sand Content in Filling Aggregates Mix *r* vs Cement Paste Volume V_{CP}.

In order to provide the required parameters of filling aggregates, it is necessary to determine correctly the structure and mode of operation of process equipment

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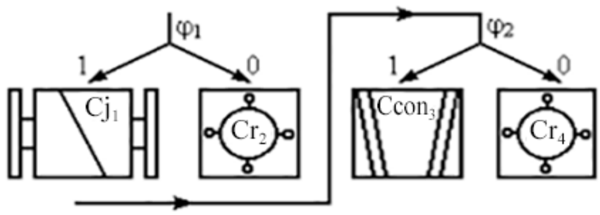
a)



b)

Card Nos	Point Nos	Control actions				Card Nos	Point Nos	Control actions			
		φ_1	S_{J1}; V_{R2}	S_{C3}; V_{R4}	φ_2			φ_1	S_{J1}; V_{R2}	S_{C3}; V_{R4}	φ_2
1	1	1	$S_{J1} = 40$	$S_{C3} = 15$	1	5	9	1	$S_{J1} = 40$	$V_{R4} = 45$	0
	2	0	$V_{R2} = 45$	$S_{C3} = 15$			10	0	$V_{R2} = 45$	$V_{R4} = 45$	
2	3	1	$S_{J1} = 100$	$S_{C3} = 15$	1	6	11	1	$S_{J1} = 100$	$V_{R4} = 45$	0
	4	0	$V_{R2} = 20$	$S_{C3} = 15$			12	0	$V_{R2} = 20$	$V_{R4} = 45$	
3	5	1	$S_{J1} = 40$	$S_{C3} = 50$	1	7	13	1	$S_{J1} = 40$	$V_{R4} = 20$	0
	6	0	$V_{R2} = 45$	$S_{C3} = 50$			14	0	$V_{R2} = 45$	$V_{R4} = 20$	
4	7	1	$S_{J1} = 100$	$S_{C3} = 50$	1	8	15	1	$S_{J1} = 100$	$V_{R4} = 20$	0
	8	0	$V_{R2} = 20$	$S_{C3} = 50$			16	0	$V_{R2} = 20$	$V_{R4} = 20$	

Figure 2. Two-Stage Crushing Diagram with Application of Two Gate Bins:
a) Layout of Crushers; b) Control Variants.

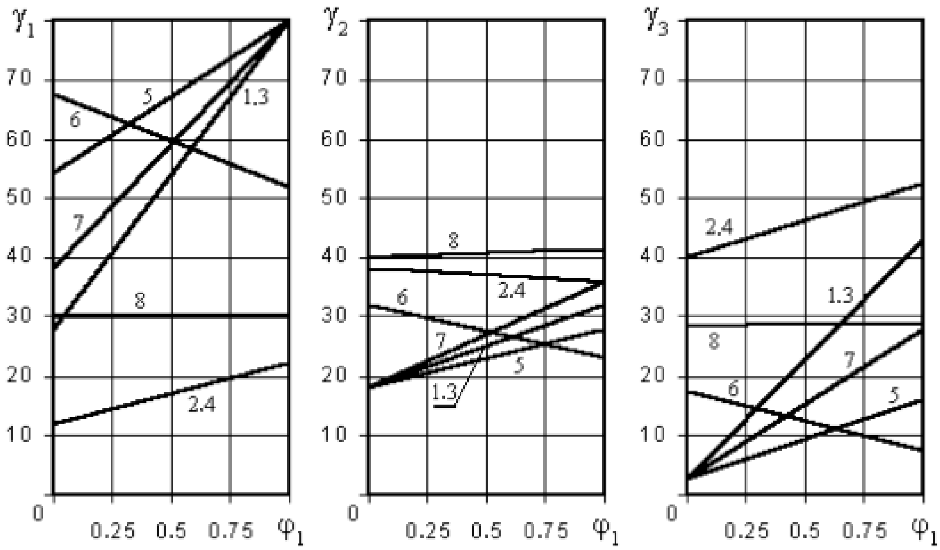


Figure 3. Output of Crushed Stone Fractions in Two-Stage Closed-Cycle Crushing Process.

of the production line. Some researchers pay special attention to the issues of determining an optimal structure of the production line (Gimadetdinov, Ostroukh, 2014; Ilyukhin et al., 2015; Suetina et al., 2009). For instance, a two-stage crushing diagram is offered during operation (Ilyukhin et al., 2015), where the crushers with different characteristics of grain-size distribution are used at both stages: jaw and rotor crusher - at the first stage, conical and rotor crusher – at the second stage.

The researchers have presented the results of experimental tests of a diagram with two primary crushers and one secondary one (points 1–8 of Table) in the form of the following graphs (Figure 3), where γ_1, γ_2, γ_3 correspond accordingly to fine, medium and coarse crushing products.

These graphs testify to the fact that in case of using a diagram of two-stage crushing and correct adjustment of crushing units under consideration it is possible to attain a change in the balance of fractions of coarse filling aggregates within rather wide limits. In this case a conical crusher is used as a secondary crushing unit (Shadrunova et al, 2015).

Two-stage crushing scheme using centrifugal crushers

According to the experience of development of the crushing and grading equipment of Ural-Omega CJSC and NPO Center the vertical-rotor centrifugal impact crushers (hereinafter referred to as the centrifugal crushers) feature a number of advantages when using these crushers as the units of the last crushing stage (Ural-Omega CJSC, 2016, Burnashev et al., 2015):

- Final product quality: high degree of reduction; stable particle-size distribution of final product; high quality indicators of crushed product, including content of grains of isometric (cubical) shape in the entire range of coarseness within the limits of 90%.

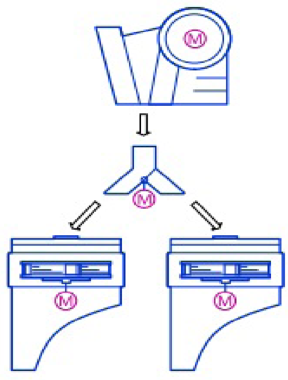


Figure 4. Two-Stage Crushing Diagram with the Use of Jaw Crusher and Two Centrifugal Crushers.

- Reliability: reduced wear of mechanical components due to lining with a crushable material; unbreakable inclusions, commensurate with the size of the power supply, do not lead to breakages and do not require stopping the work.
- Cost effectiveness: low operational costs; equipment utilization rate reaches 0.9; low power intensity; high reparability and ease of maintenance.
- Mobility: it does not require special foundations and can be installed on the aerodrome concrete slabs.

The particle-size distribution of the centrifugal crusher crushing products changes depending on the rotational speed of an accelerator adjustable by means of a frequency converter (Gazaleeva et al., 2019).

Thus, the following task can be worded: control of particle-size distribution of the two-stage crushing products with the use of two centrifugal crushers featuring different technical characteristics and/or adjustments at the second stage (Figure 4).

Evaluation of the feasibility of using two centrifugal crushers according to the results of experiments

In order to check the possibility of effecting such a control, the data of laboratory tests conducted at Ural-Omega CJSC have been analyzed. The test results have been selected for analysis, where the gravel size fraction of 5–20 mm has been crushed at centrifugal crushers DTs-0.4 with self-lining of material being crushed and DTs-0.36 with metal impact plate with different linear rotational speeds of the crusher accelerator (V, m/s). The test data are shown in Tables 1–3:

Table 1. Yields by weight.

Crusher type	V, m/s	Yields of fractions by weight, %			
		0–5 mm	5–10 mm	10–15 mm	10–15 mm
DTs-0,4	56	49.1	25.2	21.3	4.3
	65	53.9	25.9	16.8	3.4
	80	63.7	21.3	12.3	2.7
DTs-0,36	70	48.1	31.3	18.1	2.5

Table 2. Sand grain compositions.

Crusher type	V, m/s	Mк	Sieve residues	Sieve residue with mesh, mm, %					
				2.5	1.25	0.63	0.315	0.16	Bottom
DTs-0.4	56	3.54	Individual	43.2	20.3	11.5	8.0	6.1	10.9
			Full	43.2	63.5	75.0	83.0	89.1	100.0
	65	3.37	Individual	35.4	23.1	13.9	9.2	7.0	11.4
			Full	35.4	58.5	72.4	81.6	88.6	100.0
	80	3.09	Individual	26.0	25.7	15.3	10.8	8.4	13.8
			Full	26.0	51.8	67.1	77.8	86.2	100.0
DTs-0.36	70	3.84	Individual	48.3	23.1	11.2	6.2	4.2	7.0
			Full	48.3	71.4	82.6	88.8	93.0	100.0

Table 3. Qualitative indicators of crushed stone made of gravel.

Crusher type	V, m/s	Size fraction, mm	Content of crushed grains, %	Flakiness index, %	Crushed stone group	Loss of mass during crushability test, %	Grade with respect to crushability
DTs-0.4	56	5-10	52	5.2	1	2.5	1000
		10-15	25	3.7	1	5.0	1000
	65	5-10	67	3.4	1	2.6	1000
		10-15	37	1.9	1	4.1	1000
	80	5-10	71	1.8	1	2.1	1000
		10-15	41	2.8	1	4.3	1000
DTs-0.36	70	5-10	73	12.0	2	2.9	1000
		10-15	53	5.2	1	5.1	1000

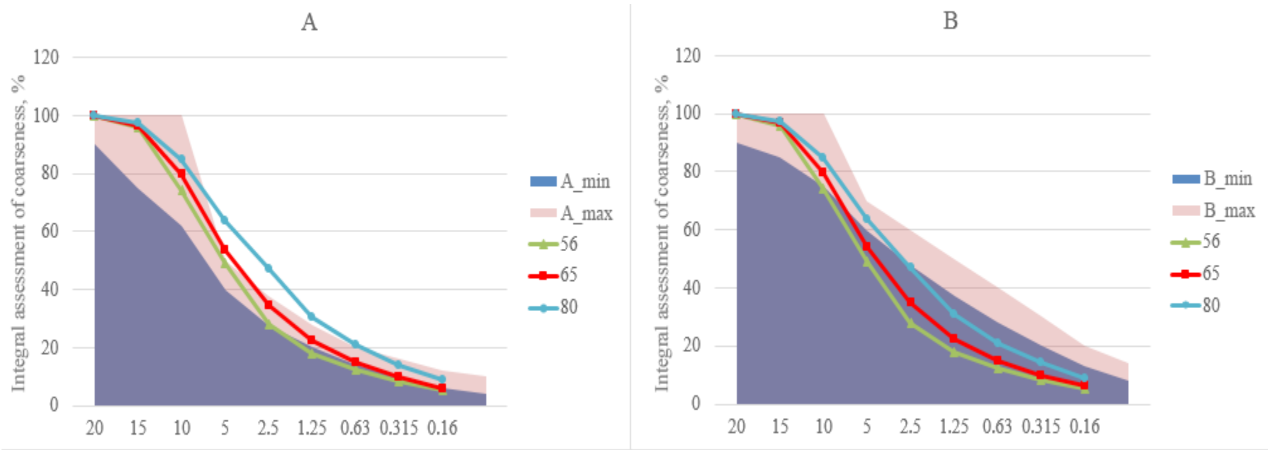


Figure 5. Integral Curves of Particle-Size Distribution for DTs-0.4 at Different Velocities Under Condition of Producing Filling Aggregates for Upper Layers of Asphalt Concrete pavement of A and B Types.

Let us give consideration to the test results in the context of producing the filling aggregates of the specified grain-size distribution for the upper layers of asphalt-concrete pavement according to GOST 9128-2013 (Federal center for rationing, standardization and technical conformity assessment in construction, 2013) (Figure 5).

The demonstrated data show that DTs-0.4 makes it possible that the required particle-size distribution of filling aggregates of medium size fractions (5–20 mm) for mixes of A type, the same as for the mixes of B type, but the yield of fine size fractions (0–5 mm) is to be increased for B-type mixes. In this case it should be noted that the manufactured products correspond to the first class with respect to flakiness index, i.e. they feature high quality.

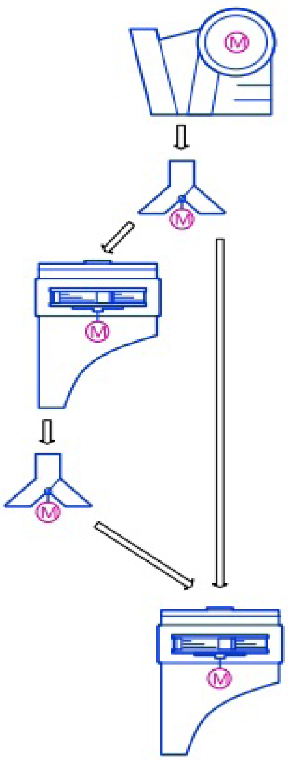


Figure 6. Two-Stage Crushing Diagram with the Use of Jaw Crusher and Two Centrifugal Crushers (Variant 2).

A similar analysis of the particle-size distribution of crushing products DTs-0.4 for B-type filling aggregates has shown that it is possible to select a mode, where the specified indicators will be ensured (of the order of 70 m/s). In order to produce mixes of D and E types, where the size fractions of 10–20 mm are absent, it is necessary to carry out a repeated crushing. Thus, the following crushing diagram is considered to be more reasonable (Figure 6). This crushing diagram will help implement different modes providing production of the specified particle-size distribution.

If it is necessary to obtain mix of A or B type, the source material is to be fed from the jaw crusher to both centrifugal crushers, which must feature equal rotational speeds of an accelerator (50 or 70 m/s, accordingly). It is also possible to produce mixes of A and B type in a specified balance simultaneously in the way of controlling material feed from the jaw crusher by means of flows distributor.

If it is necessary to obtain mix of C, D and E types, it is practical to get it by means by means of successive crushing, i.e. the material from the jaw crusher should be fed to one centrifugal crusher only. Apparently, it is possible to provide production of C-type mix at low speeds of a rotor of both centrifugal crushers, and mixes of D and E types – at high speeds.

The selection of the variant of the organization of the technological line and crushing parameters

Definitely, the particle-size distribution of crushing products depends on many factors, and an example being considered does not make it possible to guarantee production of all types of mixes using any material as well does not cover production of mixes, e.g., for the bed courses of asphalt concrete pavements (since the coarseness of feeding DTs-0.4 shall not exceed 20 mm).

In order to study the capabilities of the proposed crushing diagram, the additional experiments are required (Matveev et al., 2018).

However, the provided data demonstrate a possibility in principle to get the required particle-size distribution of

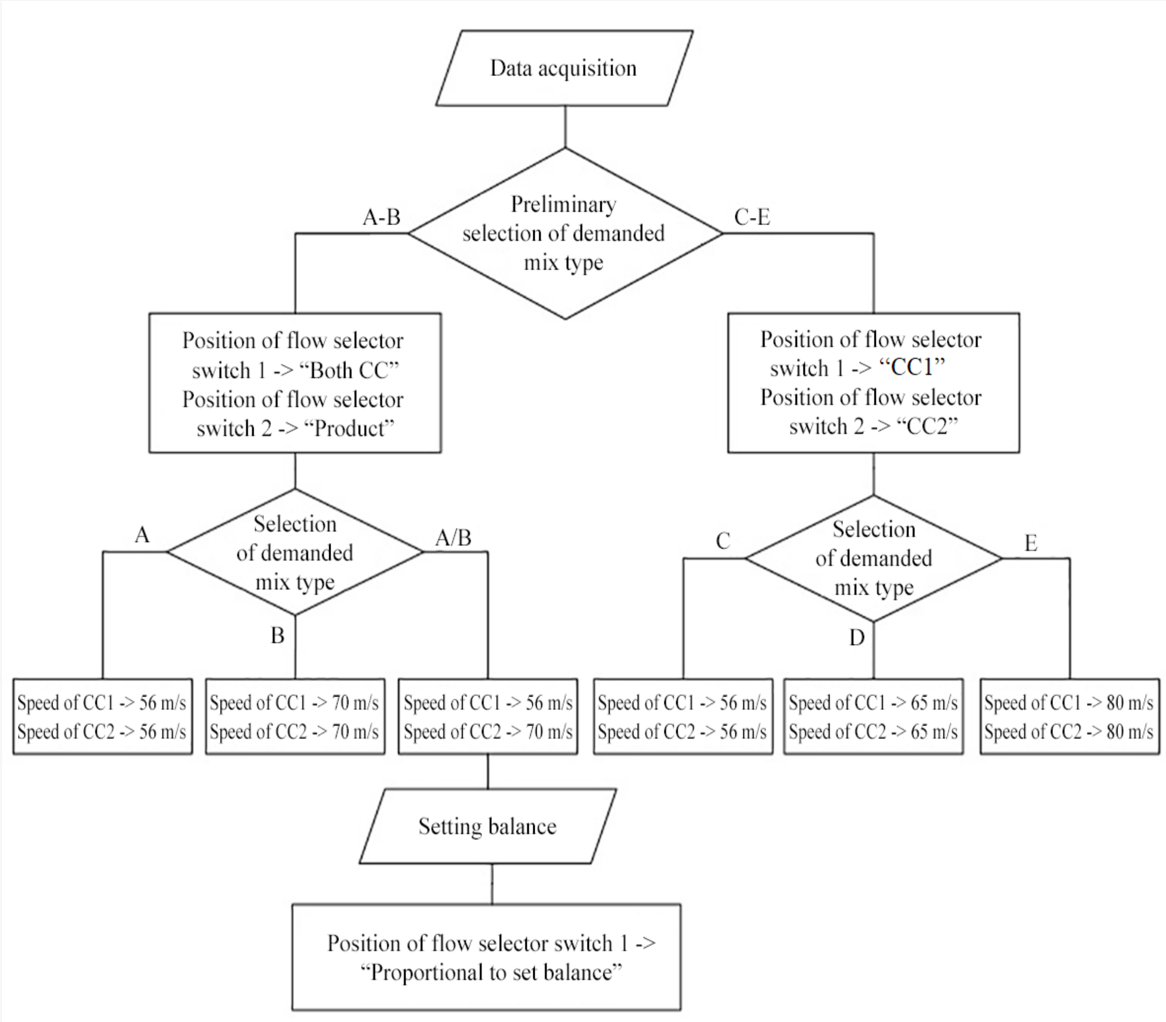


Figure 7. The block diagram of the selection of options for the organization and crushing parameters for the proposed technological scheme.

crushing products using the proposed method. Besides, the analysis of laboratory tests on crushing gravel and granite shows the similar results.

An important peculiarity is a fact that the crushing products correspond, as a rule, to the first class with respect to flakiness index.

Thus, one can articulate the following variant of algorithm of crushing process control according to the proposed diagram (Figure 7).

The demonstrated block diagram illustrates the control logic. Definitely, the speeds of accelerators of centrifugal crushers are to be selected according to data about the material, equipment, etc.

Apart from the process advantages an offered approach helps attain a number of operational advantages:

- Common hardware components of the units make it possible to keep a two-times smaller stock of fast-wearing parts;
- Possibility of quick re-adjustment of centrifugal crusher operating mode will help not to stop one of the units during repair or preventive maintenance of the second unit.
- Identity of assemblies of the units simplifies the personnel training on operation and scheduled maintenance.

Thus, the offered method of production organization will help to increase the equipment reliability as a whole and reduce downtime as a result of emergencies and scheduled maintenance.

The analysis of statistical data with respect to crushing process in high-performance centrifugal crushers with the coarseness of feed up to 70 mm constitute the following task in this direction in order to prove serviceability of the proposed diagram at the production facility as well as implementation of the control system making it possible to effect the offered method. In case of using DTs-0.4 a task of designing a mobile line in the form of a unitized package seems to be relevant due to equipment portability and low power.

Conclusion

A method of crushing process organization has been offered making it possible to increase production qualitative and quantitative characteristics as well as its operational reliability, which is testified by the analysis of laboratory tests as well as by the general algorithm of process control when using this method.

The lines of scientific and engineering activity have been defined for the development of the offered control method.

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References

Burnashev R.E., Ryabchikov M.Yu., Grebennikova V.V., Ryabchikova E.S. (2015). The study of probable approaches to controlling the centrifugal-type crushers manufactured by Ural-Omega CJSC factoring in the product quality. *Vestnik of Nosov Magnitogorsk State Technical University*, № 1 (49), pp. 82–89.

Gazaleeva, G.I., Bulatov, K.V., Levchenko, E.N. (2019). The choosing special methods of disintegration for very complicated rare ore. In: *Proceedings of 29th International Mineral Processing Congress*, pp. 258–268.

Gimadetdinov, M.K., Ostroukh, A.V. (2014). Determining a List and Sequence of Solving Tasks of Automated Crushing and Grading Production. *Automation and Control in Technical Systems*, 4, pp. 55–61.

Federal center for rationing, standardization and technical conformity assessment in construction (2013). *Asphalt-and-Concrete, Polymer Asphalt-and-Concrete Mixes, Asphalt Concrete, Polymer Asphalt-and-Concrete for Motor Roads and Airfields*. GOST 9128-2013. Moscow: Federal center for rationing, standardization and technical conformity assessment in construction.

Ilyukhin, A.V., Marsov, V.I., Kolbasin, A.M., Tolmachev, A.G. (2015). Determining an Optimal Structure of Process of Two-Stage Crushing of Stone Materials at Coating Plants. *MADI Bulletin*, 3 (42), pp. 102–109.

Matveev, A., Lebedev, I., Lvov, E., Osipov, D., Gavriliev, D., Sleptsova, E. (2018). Possibility of implementation of dry technology of gold-bearing ores roughing: Case study of "gurbey" deposit. *E3S Web of Conferences*, 56, 03012. DOI: 10.1051/e3sconf/20185603012.

Shadrunova, I.V., Gorlova, O.E., Kolodezhnaya, E.V., Kutlubaev, I.M. (2015). Metallurgical slag disintegration in centrifugal impact crushing machines. *Journal of Mining Science*, 51 (2), pp. 363–368. DOI: 10.1134/S1062739115020210.

Suetina, T.A., Nanazashvili, I.Kh., Zolotarev, S.Yu. (2009). Automated System of Two-Stage Crushing. *Stroitelnye Nauki*, 4, pp. 85–87.

Sukhodoeva, N.V., Babitsky, V.V. (2009). Methods of Designing Concrete Composition. *Bulletin of the Byelorussian-Russian University*, 2 (23), pp. 167–176.

Ural-Omega CJSC (2016). *A Page Comprises Data About All Types of Equipment Supplied by this Company*. Available at: http://www.uralomega.ru/. (accessed on: 11.02.2019).

NON-DESTRUCTIVE MONITORING AND TECHNICAL EVALUATION CONDITIONS OF THE MONUMENT ALEXANDER III

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Abstract

The article presents the methods of non-destructive testing and evaluation of monuments of cultural heritage, verified by the example of technical analysis of the structure and the defective condition of the monument to Alexander III (St. Petersburg). The methodology includes a set of scientific and technical activities and consists of several blocks of analysis of the composition of materials and design features: visual-optical, capillary, acoustic-ultrasonic, acoustic-ultrasonic pulsed, thermal-imaging, X-ray fluorescence and metallographic.

The main results are the assessment of the technical condition of the monument to Alexander III, contributing to the development of restoration activities and conservation. The practical significance of the work is the accumulation of data about the structure and material of the monument, the development of recommendations for further research and restoration activities of similar objects of historical, cultural, and architectural value.

Keywords

Non-destructive control methods, flaw detection, preservation of cultural heritage, cultural and architectural monuments.

Introduction

Numerous methods of researching monuments of sculpture and architecture are diverse. They are based on a wide variety of scientific and technical methods and are very interesting and time-consuming, often yielding unexpected results, since almost all monuments do not have technical documentation, were made in a single copy and reflect the level of technical achievements of teams of authors, individual authors and characterize the level of technical achievements and standard technical solutions of the era, which they represent.

By virtue of the above features, the method of monitoring the technical condi-tion of monuments of sculpture and architecture may differ dramatically from the methods of technical control in engineering and instrument-making, but also has much in common in terms of the methods used, ways of their implementation, processing and presentation of results.

Subject, tasks and methods

This paper presents a research methodology based on non-destructive methods of controlling materials, structure and technical condition of monumental sculptures by the example of the results of a technical survey of the monument to Alexander III.

The purpose of the research was to establish the technical condition and design features, including internal structure and its defective state to search for the solution to the problem of relocating the monument to a new exhibition site, as well as to accumulate factual material about the structure and material of the monument and make recommendations for further restoration measures (Nagaeva et al., 2018). It is worth noting that during the primary visual inspection of the monument to Alexander III, it was stated that during previous relocations significant defects in the material of the base, namely the formation of a large crack in the plinth, about a meter long, were found that could have unpredictable consequences for the integrity of the monument itself during its transportation and further storage. Preliminary investigations showed that the monument (herein-after the “monument” means its bronze cast part without a pedestal and lost parts: horse reins, which were in Alexander III’s hand, etc.) (State Duma, 2019) consists of five parts: the rider with

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the saddle, the front part of the horse, the back part of the horse, the horse's head and the plinth.

The monument is a relatively young work of cast monumental sculpture of St. Petersburg. P. Trubetskoy in his design took into account the experience of operating bronze sculptures in a humid sulfur atmosphere of the city with sharp temperature changes.

There is no steel frame in the structure of the monument, (which is present in monuments of similar mass to Peter I and Nicholas I), and therefore, the monument does not have significant defects such as long developed cracks caused by electrocorrosion between the bronze of the monument and the iron of the frame and the subsequent penetration of moisture into the emptiness of the sculpture breaking the material during freezing – defects typical of the monument to Peter I by Rastrelli.

The sculptor calculated the structural strength of the monument, but only in relation to the natural conditions of operation: many years under the influence of atmospheric phenomena (wind, snow, acid and alkaline rains of the industrial city, temperature drops), but only at rest, on a monolithic granite pedestal. The relocation of the monument was supposed only once for its installation on the pedestal in the middle of Znamenskaya Square. At the same time, the archival search did not allow to unequivocally establish whether the monument was delivered to Znamenskaya Square in assembled form or was mounted on site.

The sculptor did not assume that the assembled monument would be relocated many times, be used during the shooting of the film in the form of scenery, spend several years lying on its side in the Mikhailovsky Garden, would be subjected to a direct hit of a high-explosive bomb, be filled up with sand during the war and even in the Russian Museum would stand in the backyard for several decades without a foundation.

All of the above types of loads relate to extreme ones, and therefore, when the question of the next relocation of the monument to a new exhibition site was raised, a serious examination of the monument as a composite engineering structure with a complex, little-known previous load history was required.

First of all, it was necessary to determine the rigidity and strength of the whole structure, for which it was required to determine the structure of the monument, the material, its composition, the defective condition and based on the data obtained to predict the behavior of the structure during slinging, lifting, moving by road and to suggest a method of relocation that excludes destruction of the structure and its irreversible deformations (Rebrikova, 2008; Baranov, 2013).

The destructive method of research in this case is not applicable: any cutting and sampling, etc., is impossible, since the object of study is unique. It is possible to determine its chemical composition only on the basis of X-ray diffraction analysis of the metal scraping.

Therefore, in the present case, the main emphasis was on the use of non-destructive testing methods: flaw detection and diagnostics (Gavrilenko et al., 2008). The complexity of the scientific formulation of the problem, in this case, was also in the fact that almost all methods of non-destructive testing are calibrated. In our case, due to the uniqueness of the control object, it was necessary to develop non-destructive testing techniques excluding additional calibration.

The complex, widespread use of flaw detection methods was also due to the fact that after identifying all defects and their boundaries, the metal of the monument may have significant variability in the properties of stiffness and strength at various casting sites.

The mechanical properties of the material of the monument depend on the quantitative ratio of the components in bronze, which may be different in various places of the same casting, and even more so in different castings, intercrystalline corrosion, fine porosity of individual casting sites (as, for example, on the back of the left rear horse's leg, etc.). Not only the strength and deformability properties of bronze depend on these parameters, but also all the other physical characteristics: acoustic, electrical, thermotechnical, etc.

Knowing the values of some of these characteristics, it is possible without destroying the material of the monument to predict the magnitude of mechanical characteristics of bronze in the places of local loading of the monument that the researcher is interested in. To solve these issues in the course of the work, non-destructive diagnostic methods were used (Chistyakov, Krogius, 2014; Firsova, 2012).

In the course of the work, the optimal schemes for slinging, lifting and relocating of the monument were determined based on the results of the non-destructive testing.

Brief historical background

The monument to Emperor Alexander III (Figure 1) was built during 1900-1909 according to the project of P. Trubetskoy. The casting of the monument was carried

Figure 1. The monument to Emperor Alexander III according to P. Trubetskoy's project.

out in two places: the figure of the rider was cast in the workshops of the Academy of Arts, the rest of the details - at the Obukhov Factory [8].

The opening of the monument to Emperor Alexander III took place on May 23, 1909. The monument was erected

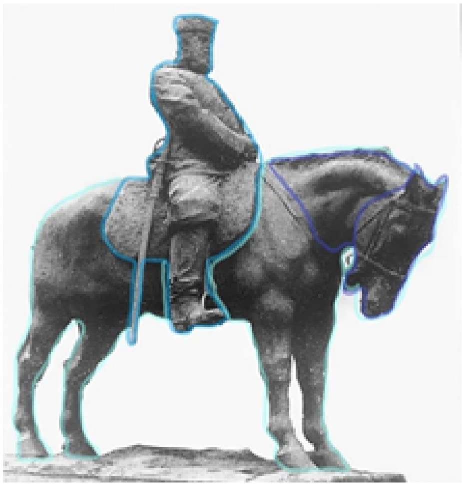

Figure 2. The scheme of elements of the monument to Emperor Alexander III.

on Znamenskaya Square.

The development and manufacture of the monument cost 1,500,000 rubles. “The emperor is depicted sitting astride a horse, in full-dress uniform of a general, the left hand holds the reins of the horse with power, but calmly, and the right one smartly rests on the side. On the front side of the pedestal facing the Nikolaevsky railway station, the inscription was made: To Emperor Alex-ander III, the sovereign founder of the Great Siberian Way” (Pedashenko, 1912). The casting of the equestrian statue was entrusted to Florentine master Robecchi (Schmidt, 1989).

The monument has caused a lot of lively and passionate disputes and almost all recognized it as unsuccessful. For example, academician A.N. Benois wrote: “One can only regret that Trubetskoy because of the lack of knowledge and technical skills in the statue he created, finally disappointed many of those who hoped for him”.

It was thanks to the striking portrait resemblance of the monument to the Emperor, despite numerous negative reviews about the monument itself, that the royal family agreed to the opening of the monument (Rogachevsky, 1965).

In the first years of Soviet power, bronze letters were removed from the pedestal and the inscription with the content corresponding the time (“Scare-crow”) was made.

In 1937 the “gates of the city” were recognized as an unsuitable place for such a monument, which was an “evil, murderous satire on autocracy”, and the monument was removed from Znamenskaya Square to the courtyard of the Russian Museum, where it was located at the time of the research (Rogachevsky, 1965).

During the war, the monument was transported to the Mikhailovsky Garden, laid on its side and covered with sand. On October 17, 1941, the monument was hit by a high-explosive bomb. Thanks to the sandy backfill, the monument did not receive any visible damage.

After the war, the monument was again returned to the courtyard of the Russian Museum.

To date, the monument is different from the pre-revolutionary state due to the following losses:

1. overhead letters of the inscription removed at the change of the inscrip-tion in the 1920s;

2. a monolithic pedestal of pink granite blocks as it was dismounted during the dismantling of the monument, sawn into pieces and used, in particular, for the pedestal of the monument to Rimsky-Korsakov.

3. separately manufactured overhead reins of a horse, which were in the rider’s left hand.

Results and discussion

Control of the material and structure of the monument

To clarify the possibility of applying loads to the monument, the occur-rence of which is possible during slinging and transportation, taking into account the identified defects in the material of the monument, its physical and mechanical characteristics, thickness in dangerous sections and bearing capacity of connections of individual elements, a complex of nondestructive testing methods was proposed (Potapov, 1980).. The complex includes the following methods:

1.visual-optical – to detect external defects, i.e. defects that reach the surface (internal or external) of the metal of the monument, as well as to determine the internal structure of the monument, the connection of its individual parts and their technical condition;

2. capillary – to determine the presence of microcracks in strained places, their actual size and orientation;

3. acoustic-ultrasonic – to determine the presence of internal defects, their boundaries and coordinates, i.e. for flaw detection;

4. acoustic-ultrasonic – to determine the thickness of the metal in the most strained places, i.e. for thickness gauging;

5. acoustic-ultrasonic pulse – to determine the physical and mechanical properties of the metal in the places of the greatest loads during lifting and relocating of the monument, i.e. for diagnostics;

6. thermal-imaging – to determine the solidity of the connections of indi-vidual parts of the monument;

7. X-ray fluorescent – to determine the chemical composition of the mate-rial;

8. metallographic – to identify the microstructure of the material.

Studies and analysis of the experience available in our country (the study of monuments to Peter I and Nicholas I in St. Petersburg) and abroad (the study of the figure crowning the Capitol in Washington) showed that the choice was made correctly.

When conducting research on the monument to Peter I, gamma flaw detec-tion was also used to determine the presence and orientation of metal fittings embedded in bronze (in particular, in the legs of the horse). In our

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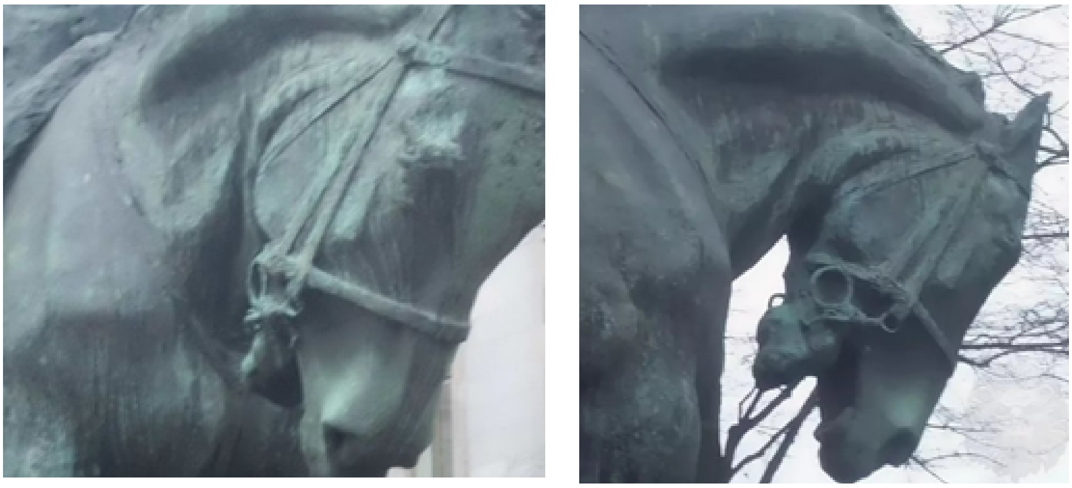

Figure 3. The scheme of elements of the monument to Emperor Alexander III – the head of the horse.

case, such a task was not set, and all other issues were solved using the methods proposed above. In addition, it is necessary to take into account that in order to conduct gamma flaw detection, special security measures are required and specialized services should be involved. Therefore, carrying out flaw detection by this method was impossible in the conditions of close proximity of premises with a large number of people.

The study of the structure of the monument, the connections of its parts and individual defects

No documents on the structure of the monument have been preserved. Therefore, it was not even clear whether the monument has a steel frame inside a hollow structure (as in the monument to Nicholas I or a steel frame in separate bearing elements, as in the monument to Peter I).

With the help of a special technical flexible controlled endoscope, the in-ternal structure of the monument and the state of fasteners were examined. It was found out that the monument consists of four parts: the head of the horse, the front part of the horse, the back part of the horse, the figure of Alexander III.

The front and back parts of the horse are connected with two mechanical-ly machined half-flanges with the help of bolts with nuts (presumably M14).

The inner line of the conjugation of the horse with the figure of Alexander III has a complex contour. The figure is bolted (presumably with M12 bolts) with nuts. The same figure shows the sketch of the connection of the horse with the figure.

The horse's head is connected to the horse's body with bolts (15 pieces), the heads of which were cut off after mounting. The upper part of the coupling has a gap of 2 mm. In the lower part of the interface, corrosion products and traces of unidentified seal material are visible.

The horse's hooves are inserted into the grooves of the plinth. Through the lower part of the body, holes were drilled and pins were inserted (supposedly 12 mm in diameter). Besides, the hooves are welded (sealed) around the perimeter. Ultrasonic testing revealed significant heterogeneity and non-penetration.

With the help of a thermal imager, significant gaps (up to 35%) were identified along the line of conjugation of the horse's head (weight more than 1.5 tons, length 1.7 meters).

The monument is patinated, has a fairly well-preserved exterior surface, virtually no corrosion damage. Only in some places there are small foci of metal oxidation: the greening of different shades.

Through holes. There are several holes in the monument: technological, from bullets and fragments and casting defects.

Technological holes with a diameter of 25 mm are located on the plinth and in the lower part of the horse's belly. The metal around the hole is solid.

The monument has several casting defects.

There is a hole of irregular shape measuring 50x60 mm, partially filled with zinc in the horse's head between the ears. Bronze around the hole is thinned to 5-10 mm.

There is a hole with a diameter of 6 mm on the rider's boot. There is an oval opening measuring 12 × 7 mm in the right thigh of the horseman. There is a hole of 25 × 15 mm on the outside of the boot, the hole in the top of the fist of 80 × 20 mm. The metal around the hole is thinned. There is a threaded hole of M10 size in the index finger.

There are cast defects such as scabs caused by penetration of molding mixture pieces into the metal during the hardening process. One scab with a size of 70x40 mm and a depth of 30 mm was found in the lower part of the arm.

Cavities. There are small cavities on the surface of the monument. The largest number of them is in the front part of the horse's chest of 5–15 mm long, 5–10 mm deep.

Cracks. There are microscopic cracks in the monument. There is a deep crack in the plinth. It starts at a distance of 215 mm from the front of the plinth on the left side and goes to the right side at a distance of 230 mm from the front part. It was welded (or smelted) and calked at a distance of 580 mm from the right side.

Ultrasonic control showed the absence of confluence between the embedment material and the base metal in some places.

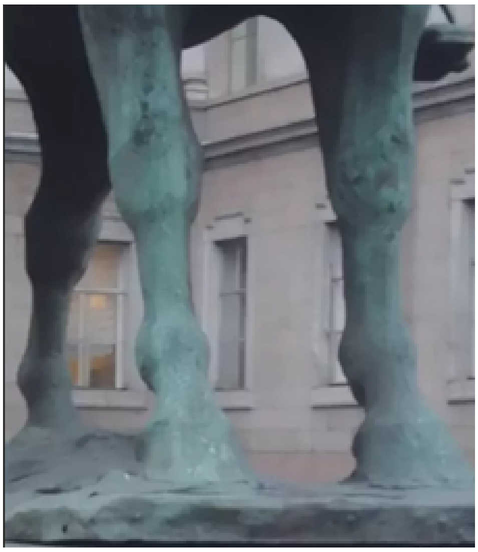

Figure 3. The scheme of elements of the monument to Emperor Alexander III – the front part of the horse.

Seals. The sealing of the hole with a diameter of 85 mm in the horse's mouth with a zinc-based alloy is in good condition.

A large number of seals is in the rider's figure. Obviously, a fragment of 100 × 200 mm is welded in the upper part of the saddle. On the right side of the saddle there is a seal with bronze 130 × 120 mm in size. There are seals in the plinth.

The use of the endoscope allowed examining in detail the condition of bolted connections in the horse's belly. The advantage of the endoscope is the presence of an operator-controlled head equipped with a magnifying lens, so the place of control is examined in an enlarged form and even minor defects are detected.

This allowed us to verify the good quality of bolt connections. It should be noted that the advantage of the endoscope is at the same time its disadvantage as the use of a microlens leads to the fact that the field of view and depth of field are very small, so the method is very laborious and tedious for the operator. The method, in such an implementation, can only be recommended for surveying individual sites. Otherwise, television endoscopes should be used.

Figure 4. The scheme of elements of the monument to Emperor Alexander III – the back part of the horse.

The survey of the entire internal structure of the monument was carried out visually with the help of a special purpose tubular halogen illuminator and a system of mirrors. There are no special openings for inspecting the monument (as, for example, in the monument to Nicholas I, where there is a special hatch). Therefore, the existing minor openings – through defects – had to be used. Illuminators entered the monument in two ways.

1. A halogen lamp KIM-100 with a power of 100 W was inserted on a tel-escopic rod through a hole in the lower part of the horse's belly, designed to drain water. Inspection of the internal cavity of the monument was carried out through a similar opening located next to it through the hole in the rider's left boot and through the hole in the upper part of the rider's left hand holding the reins. The inner surface of the monument is very dark, covered with a layer of oxides and dust and therefore strongly absorbs light. Thus, it was possible to establish the absence of internal metal reinforcement and the presence of bolted joints between the elements and their number.

2. For a more detailed examination of the internal structure of the monu-ment, after it had been found to be hollow, it was decided to use a 1300 W special-purpose halogen lamp KG 220-1300-3, the distinctive feature of which is a rod-like design with the diameter of 8 mm, which allowed to enter it into the monument through the hole in the rider's left fist. Thus, the internal struc-ture of the monument, the method of connecting the individual parts and the presence of defects reaching the internal surface of the monument were studied in detail. However, it was not possible to fully examine the inner surface of the horse's legs. Even the use of special mirrors and lenses did not allow a peek through the existing holes to look inside the horse's legs, into the area of the hock joint, i.e. to the place where a large cluster of porosity was found outside.

Defects of microscopic size, most often – cracks, cannot be detected visually, but they can be stress concentrators and, therefore, are also subject to detection. The greatest accumulation of microcracks by the method of microscopy was found around the rivets (or screw caps) securing the horse's head to the body. Since the horse's head is a console weighing about 1.5 tons, the connec-tion was subjected to the most careful control. The capillary method is most suitable one for the detection of defects of this type.

In our case, due to the poor (from the point of testing) condition of the outer surface of the monument, it was impossible to detect defects as small as micrometers, and there was no need for this, since they could affect the bearing capacity of the monument at loads close to critical, and such loads should not occur in the monument during lifting and transportation. Defects in the form of cracks with an opening of tens of micrometers and more were detected reliably.

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Figure 5. The scheme of elements of the monument to Emperor Alexander III – the figure of Alexander III.

The presence of microscopic cracks around the holes along the martingale was determined, in which there were screw inserts that fasten the horse's head with the body. This was another reason for recommending reinforcement of the horse's head during transportation. Aerosol penetrants of the Italian company Namikon, which allowed detecting very small cracks, were used for the control, but in those places where the surface condition allowed for thorough cleaning. In other places, the capillary method was implemented using the so-called "kerosene sample method", in which kerosene was used as a penetrant, and chalk – as a developing substance. The method has a much lower sensitivity, but works well on a rough, untreated surface, which is almost the entire surface of the monument.

After detection and classification of the defects that reached the surface (internal or external) in the most loaded (during lifting and transportation) places, it was necessary to determine the thickness of the metal and the absence of internal defects: pores, voids, slag and earthen inclusions, etc. For these purposes, the acoustic ultrasonic flaw detection method was used. To effectively apply this method, it is necessary to correctly determine the optimal modes of flaw detection, methods for inputting and receiving ultrasonic vibrations, methods for processing the results, and then choosing a device or several mutually complementary devices that meet these requirements.

The main parameters that determine the test effectiveness in the case under consideration and the principles of their choice (Aleshin, 1989). The correct choice of UT frequency is of great practical importance to obtain the necessary sensitivity during the test. The higher the frequency, the shorter the length of the elastic waves in the controlled product and the better the conditions for their reflec-tion from defects. With an increase in the frequency of sounding, the directivity of radiation and reception increases, due to which the ratio of the energy re-flected from the defect to the total energy introduced into the product, grows. Moreover, it helps to increase the sensitivity of control. However, as the fre-quency rises, the attenuation coefficient of elastic waves in the controlled object increases, the conditions for the passage of waves through the input surface deteriorate, and the intensity of reflections from grain boundaries and non-uniformity of metal, which are not defects, grows.

When inspecting the details, the UT frequency is determined mainly by the attenuation coefficient, the level of structural reverberation of the material, and the dimensions of the product being monitored. Knowing these characteristics, it is possible to estimate and choose the optimal frequency, which will ensure the greatest sensitivity of the control with minimal energy loss to scattering and absorption by grains of metal.

In metals with pronounced anisotropy (copper, zinc), which occurred in the case under consideration and in some alloys with complex phase composition, ultrasound is strongly scattered. The attenuation coefficient for these metals is ten times higher than for alloys with a small degree of elastic anisotropy. As a rule, the sounding of such metals is accompanied by structural reverberation - gradual attenuation of ultrasonic testing due to multiple repeated reflec-tions of waves from the grain boundaries of metal. As a result of this, interference may appear on the flaw detector screen, which significantly complicates the UT inspection. If the level of structural reverberation is small, then details can be sounded at a sufficiently high frequency. Otherwise, the frequency must be significantly reduced. In the case described, the best results were obtained using piezoelectric transducers with an operating frequency of 0.6 MHz.

When testing the material of the monument, the situation was largely complicated by the presence of an unpredictable surface corrosion layer a hundred years old, the removal of which was impossible under the conditions of work. In addition to corrosion, the metal of the monument was also covered with a layer of patina, which was an artificially applied layer of a rather thick oxide film. All this greatly hampered the input and reception of ultrasonic waves, and the interpretation of the results.

Thickness measurement was carried out using a portable, easy-to-use UT-93P thickness gauge, which has the ability to tune out interference, displays the results in a digital form on a liquid-crystal digital display and has an indication of the reliability of contact with the product being monitored. The manufactur-er produces a device configured to control steel products, so for the work it was necessary to reconfigure it to control bronze. Eentering and receiving a UT in the material of the monument was significantly difficult.

Reliability of indications when carrying out thickness gauging is ensured only with reliable input and reception of ultrasonic testing. In our case, as already noted, the monument has practically no flat areas with good surface cleanliness, is fully cov-ered with patina, corrosion products and contamination. According to the con-ditions of work, the cleaning of the monument was not allowed, which could spoil its appearance, so it was necessary to carry out control in the above con-ditions, which did not always allow achieving stability of the readings (Gubenko et al., 1980). For measurements, P112-10-6\2-AVT-05 converter was chosen, designed for a rough, uneven surface, with a contact pad of 6 mm in diameter.

According to the slinging scheme proposed and agreed with the customer, it was necessary to determine the metal thickness at the points of application of the distributed load from soft slings to the horse's belly (to prevent punching) and to the thinned sections of the legs (to prevent tearing under the plinth and legs).

The most thinned places of the monument were identified and the ac-tual loads were calculated. Flaw detection was performed using UD2-12 and UD12-22 ultrasonic domestic flaw detectors. The control was carried out according to a specially developed methodology. Ultrasonic inspection of weld joints of the plinth and connections of the horse's legs gave disappointing results. As already noted, it was not possible to reliably determine the method of connection, but it was found that the connection was not equal in strength to the rest of the material.

Nearly all welds have lack of fusion throughout the cross section of the seams; there is a clear boundary between the base and the weld metal. The connection cannot be attributed to structural ones as it is purely decorative in nature and should be supported when lifting the monument, as indicated in the slinging scheme.

Ultrasonic diagnostics made it possible to determine the strength and de-formative properties of the metal in the above places. In our case, the problem was somewhat facilitated, since by the time the work was carried out, there had already been obtained the results of the chemical analysis of the material and the values of the strength and deformative properties of the material in this place (Potapov et al., 2016). Having measured the UT speed in the same place and then measuring it in other places of interest, the elasticity modulus variation was determined from the velocity variation.

Measurements were made using UKB-1M ultra-sonic velocity meter and UD2-12 flaw detector with a velocity measurement mode.

However, the ultrasonic inspection speeds in all five parts of the monument were measured. The average speed was 5120 meters per second. No dangerous anomalies, indicating a change in the struc-ture of the material of the monument, significant microcrystalline corrosion or fracturing were detected. The metal in all places was quite homogeneous.

The study of the chemical composition of the alloy and its structure, as well as the embedding material of defects.

The monument to Alexander III is cast from the so-called green art bronze. 8 tons of bronze were used for casting. The chemical composition was determined by the X-ray fluorescence method using Philips PW-1220C scanning spectrometer according to STP 90.208-83 method with the help of "Centrolab" association. The following val-ues of the mass fractions of the components were established: tin 8%, zinc 8%, lead 1%, the rest is copper. The grade, according to modern classification, could be called OCS-8-8-1.

Of the existing standard art grades, it is close to BH-1, which has a slightly lower content of alloying.

The strength of the metal of the monument is about 150-200 MPa, and the relative elongation – 8-12%.

The alloy has good casting properties (zinc additives), increased density and good processability (lead additives).

A metallographic study, also conducted with the involvement of employees and equipment of "Centrolab" association, allowed to establish that the material of the monument has developed dendritic segregation and is a α-solid copper solution + eutectoid ($Cu_{31}Sn_8$ + α).

According to the results of the X-ray fluorescence analysis, the material for embedding defects is zinc (Zn – 98.6%, Pb – 1.2%).

Conclusion

To preserve the historical and cultural heritage, a regular survey of the technical condition of the monuments is necessary not only in preparation for extreme conditions, such as moving, transporting and changing the storage conditions of the monument, but also to assess its current state for timely restoration and conservation, as well as the preparation of technical documenta-tion such as passports of objects of history. At the same time, methods of non-destructive testing of quality of materials and structures are stipulated as spar-ing and not leading to the occurrence of irreversible phenomena of product destruction.

The technique, representing a set of methods for non-destructive testing, the study of the technical condition of objects of decorative and applied art, is aimed at identifying defects in materials and structure, their physical and me-chanical characteristics, thickness in dangerous sections and the carrying ca-pacity of the connections of individual elements, namely:

- visual-optical method is applicable when determining external defects, as well as for determining

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the internal structure of the monument, connections of its individual parts and their technical state;

- capillary method is used to determine the presence of microcracks in strained places, their actual size and orientation;
- acoustic-ultrasonic method is applied when detecting internal defects, i.e. in case of flaw detection, as well as to determine metal thickness in the most strained places, i.e. for thickness gauging;
- acoustic-ultrasonic pulse method is used when determining physical and mechanical properties of metal, i.e. for diagnostics;
- thermal imaging method is applicable when determining the quality of the connections of individual parts of the product;
- X-ray fluorescent method – to determine the chemical composition of materials;
- metallographic method is used when analyzing the microstructure of materials.

Thus, timely analysis of the technical condition of materials and structures of cultural heritage monuments contributes not only to the accumulation of scientific and technical data for assessing the dynamics of the state of elements, but also to the development of scientific and restoration potential to preserve objects of historical, cultural, architectural value.

It also helps to accumulate factual material about the structure and materials of monuments for working out of recommendations for further research and restoration of similar items.

References

Aleshin, N.P. (1989). *Methods of acoustic control of metals.* Moscow: Mashinostroenie.

Baranov, V.V. (2013). On the question of the authenticity and safety of the royal gates of the "VN Laurina group". In: *Proceedings of the international scientific and methodical conference "Research on the conservation of cultural heritage"*, pp. 51–61.

Chistyakov, A.N., Krogius, M.E. (2014). *Typology of the destruction of cultural monuments.* St. Petersburg: SPbKO.

Fomin, I.V., Zaychikova, S.Yu. (2008). Technical Means for Monitoring Temperature, Humidity and Light Regimes in Museums and Architectural Monuments. In: *Proceedings of the international scientific and methodical conference "Research on the conservation of cultural heritage"*, pp. 196–205.

Gavrilenko, L.S., Grigorieva, I.A., Gribanov, A.V., Novikova, O.G. (2008). Application of a complex of microanalytical methods for studying the composition of materials and their degradation products under the influence of external adverse factors. In: *Proceedings of the international scientific and methodical conference "Research on the conservation of cultural heritage"*, pp. 129–148.

Gubenko, L.A., Lukachev, S.V., Polyakov, V.E. (1980). Investigation of the moduli of branchwood. *Forest Journal*, 5, pp. 65–67.

Nagaeva, Z.S., Zhivitsa, V.V., Sidorova, V.V. (2018). *Reconstruction and Resto-ration of Cultural Heritage Objects*. Moscow: Buk.

Potapov, A.I. (1980). *Quality control and prediction of the reliability of structures made of composite materials.* Leningrad: Mechanical Engineering.

Potapov, A.I., Filipovsky, Y.V., Karabuta, V.S. (2016). The need for and the possibility of using ultrasound in assessing the current state of monuments from rocks. In: *Proceedings of the IV International scientific and practical conference "Innovations in transport and mechanical engineering"*, pp. 123–126.

Rogachevsky, V.M. (1965). *Monument to Alexander III.* Leningrad: Nedra, pp. 202–208.

Pedashenko, S.A. (1912). *Monuments to Alexander III.* Moscow: Partnership of the A.I. Memontov Publishing House.

Rebrikova, N.L. (2008). *Practical Guide on Diagnostics of Microbiological Damage of Art and Culture Monuments.* Moscow: KMK Fellowship of Scientific Publications.

Schmidt, I.M. (1989). *From the history of world art of Russian sculpture of the second half of the 19th-20th centuries*. Moscow: Iskusstvo.

State Duma (2019). *"On the objects of cultural heritage (historical and cultural mon-uments) of the peoples of the Russian Federation"*.Federal Law of June 25, 2002 No. 73-FZ (as amended on February 21, 2019).

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SELECTION OF CRITERIA FOR COMPARATIVE EVALUATION OF HOUSE BUILDING TECHNOLOGIES

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Abstract

Variety of house building technologies, involving the use of masonry materials, precast reinforced-concrete structures, formwork systems and modern construction equipment, contributed to the need to perform expert evaluation of their applicability in various construction conditions. Expert evaluation of house building technologies is based on a set of weighty criteria considering not only costs of resources but consumer appeal of apartment buildings as well.

The expert evaluation method represents a tool for comparison of technologies by means of the system of incomparable criteria such as architectural expression of facades, dwelling convenience, durability, structural strength and seismic resistance of buildings, capital intensity of technologies, labor intensity and costs of construction using the considered house building technologies.

Keywords

Residential construction, house building technology, labor intensity, capital intensity, number of floors, durability, structural strength, expert evaluation, criterion selection, weighting.

Introduction

A modern construction sector involving various developing house building technologies has formed in Saint Petersburg. Among technologies of constructing residential apartment buildings, most commonly used in Saint Petersburg, masonry (conventional), panel, cast-in-place as well as cast-in-place and precast construction can be mentioned. The construction sector of Saint Petersburg in the sphere of residential construction is represented by house-building factories manufacturing precast construction elements and construction enterprises providing cast-in-place and masonry (conventional) construction. Competition between construction enterprises in the sphere of residential construction in Saint Petersburg results mainly in reducing direct costs of resources and improving consumer appeal of construction products. However, when performing comparative evaluation of house building technologies, it is necessary to consider other equally important technological, economic and urban-planning criteria. Quantitative comparison of technologies is complicated by the need to evaluate consumer appeal of apartments, architectural expression of facades, capital expenditures for technology introduction into construction, and other incomparable criteria. Therefore, to compare technologies, the expert evaluation method using the system of criteria selected by the authors is adopted.

Methods

Selecting the system of criteria for comparative evaluation of house building technologies, the authors perform a theoretical study of technological characteristics related to construction of residential apartment buildings to obtain a complete set of criteria, and then assess the weight of each criterion with account for the data of an expert poll.

According to Rybnov E.I., Egorov A.N., Hejducki Z. and Ghadimian N.G. (2018), residential apartment buildings of Saint Petersburg are the most characteristic of technologies' development in national urban house building (especially in the period of organization and planning of production entities' activities under conditions of large-scale housing construction carried out since the middle of the 20th century).

Examining the brickwork in tenement buildings in the historical center of Saint Petersburg, Golovina S.G. and

Sokol Yu.V. (2018) performed an analysis of structural and technological characteristics of the masonry (conventional) construction system.

Modern masonry technologies are developing based on long experience in brickwork, using new masonry materials made of porous concretes and hollow clay blocks.

An analysis of options for construction of residential apartment buildings in Saint Petersburg was conducted by Yudina A.F. and D'yachkova O.N. (2010). As a result, specifics of residential construction in the period from the second half of the 19th century to the early 20th century were revealed. The authors of the paper also provided an overview of the house building technology as a system of industrial resources used mainly to erect load-bearing structures of a construction facility.

In his paper "Labor intensity as a criterion to evaluate efficiency of technical and technological solutions", published in 2016 in the Proceedings of the 72nd Scientific Conference of professors, teachers, researchers, engineers and post-graduate students of the Saint Petersburg State University of Architecture and Civil Engineering, Likhachev V.D. analyzed labor intensity as a criterion to evaluate efficiency of technological solutions in residential construction. Costs of labor resources depend directly on the applied construction technology (Likhachev, 2016).

Allen E. and Iano J. (2004) categorize construction technologies according to the methods of processing materials used in construction of a facility. Among basic construction materials used to erect load-bearing structures at a construction site, the following can be mentioned: masonry and concrete mixes, brick, small and large concrete blocks, precast reinforced-concrete structures, building bars, rolled sections and industrially manufactured steel structures. Among basic methods of processing construction materials when erecting load-bearing structures of a construction facility, masonry, reinforcement, concreting and installation can be mentioned.

In his DSc thesis "Integrated automation of processes for construction of industrial facilities out of cast-in-place reinforced concrete", Mintsaev M.Sh. (2009) broke down the comprehensive process of constructing reinforced-concrete structures at a construction site into processes of formwork assembly and disassembly, reinforcement and concreting of building structures. Figure 1 shows the technological structure of processes for construction of a cast-in-place residential building.

Construction of a cast-in-place residential building involves reinforcement, formwork and concreting performed in sequence. During erection of foundations and walls, at first reinforcement is installed and then formwork is assembled. Installation of a cast-in-place reinforced-concrete floor starts from formwork, and then reinforcement is carried out. In their monograph "Cast-in-place concrete. Technological basis. Concreting in winter", Kolchedantsev L.M., Vasin A.P., Osipenkova I.G., Stupakova O.G. (2016) presented data on time of concrete setting and strength gain. In case of proper curing of hardening concrete, in approximately 12–24 hours (at temperature of approximately 20°C), the formwork can be disassembled and prepared to be installed at the next section.

Usually, construction of a cast-in-place building is carried out using the flow-line method and a multi-level system for quality control of formwork, reinforcement and concreting according to the method proposed by professor Yudina A.F. (2012) in her paper "Advantages of monolithic building and some problems of its perfection".

Assembly is carried out upon erection of buildings out of precast concrete or reinforced-concrete structures. The precast construction technology significantly decreases the dependence of general construction works performed at construction sites on low winter temperatures and autumn rains. If a building is mainly constructed of cast-in-place elements, then the corresponding technology is called cast-in-place construction. If a building is constructed by means of assembling precast structures, then the corresponding technology is called precast construction. The technology of large-panel construction also falls into the category of precast construction of residential apartment buildings.

The superstructure of a building assembled of large precast reinforced-concrete panels is erected in the following sequence: at first, concrete panel trailers or other special-purpose vehicles deliver precast elements of a residential building to the construction site, then a construction crane installs the structural units in proper position. Installation of each precast element shall involve alignment and temporary fixing of the unit with braces, clamps and jigs.

Then electric welding of inserts in connecting points of precast structures is carried out. After anti-corrosion treatment of metal in connecting points, concreting of joints is performed. When concrete strength is gained, it is possible to start constructing the next intermediate floor. While the superstructure of a standard building is invariable, the substructures are affected by heterogeneous soil and hydro-geological conditions at the construction site.

In soft water-saturated soils of Saint Petersburg, bored piles and barrette piles, recommended by Gaydo A.N. for construction of cast-in-place foundations in his paper "Ways of improving technological solutions of construction of pile foundations of residential buildings under conditions of urban development" (2015), are considered to be the most efficient.

In Saint Petersburg, construction of foundations is preceded by shoring of excavations with the technology of slurry wall made of cast-in-place reinforced concrete or in a form of secant bored piles. Installation of bored piles and slurry wall can be classified as cast-in-place construction.

The technology of erecting the load-bearing frame of a building by assembling precast reinforced-concrete structures and constructing cast-in-place reinforced-concrete sections is called cast-in place and precast despite the fact that precast elements prevail, as discussed in the paper "Application of exposed concrete at erection

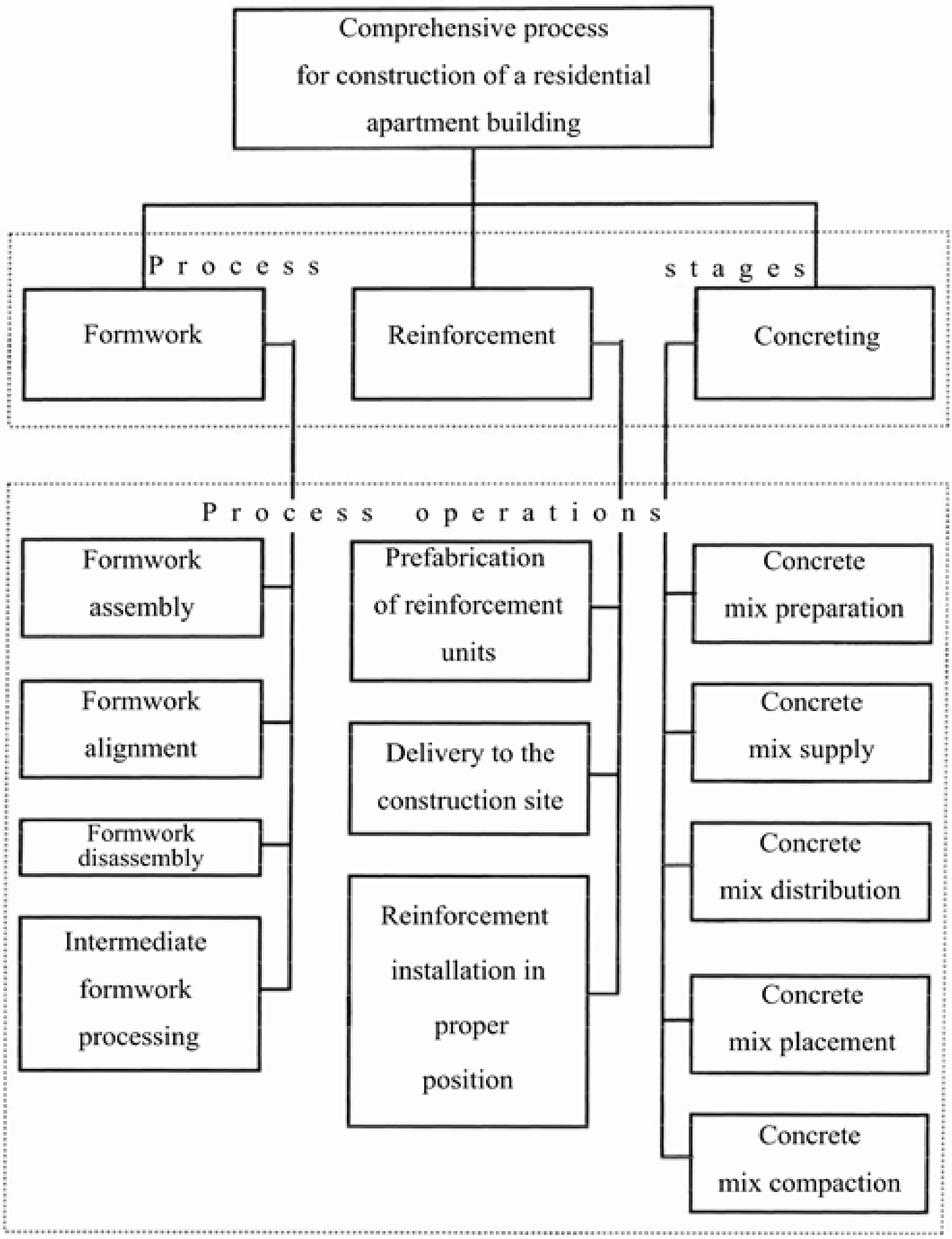

Figure 1. Technological structure of the comprehensive process for cast-in-place house building.

of monolithic buildings" by Yudina A.F. and Ponomarev M.Yu. (2016).

Construction of load-bearing walls and columns by laying brick and small blocks using sand cement or other mortar with various additives has been long used, and it is called the masonry (conventional) technology. The authors of the present paper also classify construction of brick buildings with cast-in-place or precast floors as masonry (conventional) construction.

In residential construction, modern precast buildings are usually made of panels (large panels), except for the KUB construction system and its modifications (KUB 2.5, KUB-3V) assembled of reinforced-concrete columns and panels of intermediate floors connected in a common frame with cast-in-place sections located in floor panels.

To introduce a new technology for building erection into the construction practice, investments in production facilities of construction enterprises are required. Therefore, comparing house building technologies, it is necessary to consider the capital intensity indicator, i.e. the ratio of the cost of capital used in residential construction performed according to the analyzed technology in the sphere of construction materials and sphere of construction operations to the cost of constructed residential buildings in the specific period.

Capital intensity can be evaluated using the ratio between capital expenditures and labor inputs (expenditures), i.e. specific capital expenditures per person per time unit. Besides specific capital intensity, indicators of specific labor intensity related to the house building technology, determined as the ratio between labor expenditures and construction volume in the specific period, are compared. Interrelation between construction volume, capital and labor expenditures in the specific period is represented by an isoquant curve (Figure 2), described in the monograph by Bazylev N.I. and Gurko S.P. "Economic theory" (Bazylev, Gurko, 2005).

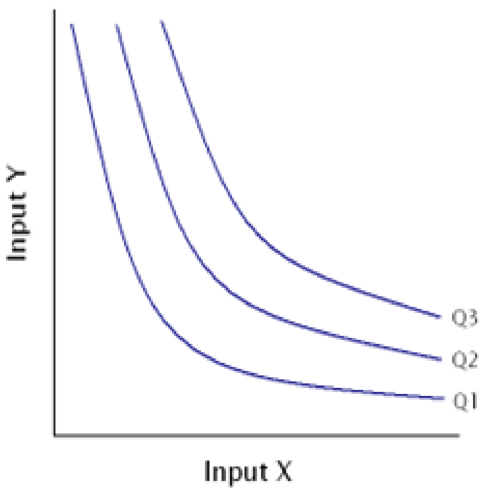

Figure 2. Isoquant curve representing interrelation between construction volume Q3 > Q2 > Q1, labor (X) and capital (Y) expenditures in the specific period.

The isoquant curve shows that an increase in residential construction volume due to production intensification is associated with investments in new capital-intensive house building technologies, resulting in labor efficiency increase and products' labor intensity decrease. Production expansion with no changes in labor efficiency is also associated with investments, but such expansion is extensive, i.e. it does not result in labor intensity decrease in residential construction and, therefore, does not increase product competitiveness due to cost saving.

The technology of panel or other precast construction represents a unified process for industrial manufacturing of standard sets of building structures and their assembly at construction sites, therefore, in evaluation of construction products' labor and capital intensity, costs for prefabrication at factories and assembly at construction sites are taken into account.

Total costs of resources spent to erect a construction facility are determined by the unit cost indicator, e.g. 1 m^2 of the residential area. The cost of 1 m^2 in a panel, cast-in-place, brick building amounts to approximately 38,000, 41,000, and 49,000 rubles, respectively.

It includes total production and construction costs related to construction of facilities according to the considered house building technology.

When comparing house building technologies, besides product costs, it is necessary to consider consumer appeal of apartments: floor level, area of rooms in an apartment, soundproofing between apartments, temperature and humidity, indoor air ventilation. Freedom in space planning in an apartment and durability of load-bearing structures in a building are essential for the developer and consumer. Opportunities of the applied technology in the sphere of architectural expression of facades are also important when accommodating a facility in an urban environment. Residential buildings located beyond the historical center of Saint Petersburg shall be high-rise, therefore, the number of floors is essential. Variety of criteria characterizing different properties of residential buildings as products of house building technologies, in relation to evaluation of not only efficiency of construction operations but capital expenditures for creation of production facilities, and consumer appeal as well, rule out direct quantitative comparison of house building technologies and force to apply the expert evaluation method using the ten-point scale for criteria measurement.

For the purposes of selecting weighty criteria for evaluation of house building technologies, criteria ranking according to their significance (weighting) is performed (Table 1).

Table 1. Ranking of criteria for evaluation of house building technologies according to their weighting.

No.	Criteria for evaluation of house building technologies	Criterion ranking on a ten-point scale
1	Architecture, heat insulation and soundproofing	
1.1	Facade architectural solutions	8
1.2	Planning architectural solutions (freedom of planning)	7
1.3	Reduced total area per apartment	6, less than 6.93
1.4	Heat insulation (approximately equal values due to insulating material)	5, less than 6.93
1.5	Soundproofing	9
2	Number of floors, structural strength, durability	
2.1	Number of floors	8
2.2	Structural strength and seismic resistance	10
2.3	Durability	9
3	Cost-effectiveness, large scale	
3.1	Capital intensity	8
3.2	Prime cost	9
3.3	Labor intensity	9
3.4	Large scale	7
3.5	Material intensity	5, less than 6.93
3.6	Industriality	4, less than 6.93
	Total points	104
	Mean score	6.93

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The criterion weight is calculated as per the following equation according to the method described by Gutsykova S.V. in her monograph "Expert evaluation method. Theory and practice" (2011):

$$a_i = f\left(\frac{\sum_{k=1}^{N} a_{ik}}{N}\right), \quad (1)$$

where N — number of experts; a_i — number of points for the i-th criterion; a_{ik} — number of points for the i-th criterion, given by the k-th expert

The mean score was calculated as the sum of points divided by the number or criteria, and amounted to 6.93 points.

When house building technologies are compared, the heat insulation criterion affects house building technology evaluation insignificantly as exterior walls of panel, cast-in-place, cast-in-place and precast, as well as brick buildings involve heat insulation. The reduced total area per apartment is also an insignificant criterion as the area of apartments does not depend largely on technologies. Apartments in panel, brick, cast-in-place, as well as cast-in-place and precast buildings have sufficient area exceeding regulatory values. Material intensity is indirectly taken into consideration in the prime cost, and, as an individual criterion, is insignificant.

The industriality level of an individual construction facility can be determined using the prefabrication factor. In its essence, the industriality criterion is irrelevant when technologies of precast and cast-in-place construction are compared.

Results

To perform comparative expert evaluation of house building technologies, the following criteria were selected:

1. Facade architectural solutions;
2. Planning architectural solutions;
3. Soundproofing of inter-apartment structures;
4. Permissible number of floors;
5. Structural strength and seismic resistance of a building;
6. Durability of load-bearing elements in a building
7. Technology capital intensity;
8. Cost of works;
9. Labor intensity;
10. Large scale (suitability for large-scale construction).

Conclusion

The selected criteria for comparative evaluation of existing house building technologies will be used in future studies of rational use of masonry, precast, cast-in-place, as well as cast-in-place and precast house building technologies in residential construction.

References

Allen, E., Iano, J. (2004). *Fundamentals of building construction: Materials and methods.* New York: J. Wiley & Sons.

Bazylev, N.I., Gurko, S.P. (2005). *Economic theory.* Minsk: Ekoperspectiva.

Gaydo, A.N. (2015). Ways of improving technological solutions of construction of pile foundations of residential buildings under conditions of urban development. *Zhilishchnoe Stroitel'stvo*, 9, pp. 12–15.

Golovina, S.G., Sokol, Yu.V. (2018). To the issue of studying the joint performance of building materials of enclosing structures in the former profitable houses of the historical center in St. Petersburg. *Bulletin of Civil Engineers*, 3 (68), pp. 112–117. DOI: 10.23968/1999-5571-2018-15-3-112-117.

Gutsykova, S.V. (2011). *Expert evaluation method. Theory and practice.* Moscow: Institute of Psychology of Russian Academy of Sciences.

Kolchedantsev, L.M., Vasin, A.P., Osipenkova, I.G., Stupakova, O.G. (2016). *Cast-in-place concrete. Technological basis. Concreting in winter.* Saint Petersburg: Lan.

Likhachev, V.D. (2016). Labor intensity as a criterion to evaluate efficiency of technical and technological solutions. In: *Proceedings of the 72nd Scientific Conference of professors, teachers, researchers, engineers and post-graduate students of the Saint Petersburg State University of Architecture and Civil Engineering*, part 1 , pp. 108–111.

Mintsaev, M.Sh. (2009). *Integrated automation of processes for construction of industrial facilities out of cast-in-place reinforced concrete*. DSc Thesis in Engineering. Moscow: Moscow Automobile and Road Construction Institute.

Rybnov, E.I., Egorov, A.N., Hejducki Z., Ghadimian N.G. (2018). Organization and planning of production structures' work at large-scale housing construction. *Bulletin of Civil Engineers*, 3 (68), pp. 98–102. DOI: 10.23968/1999-5571-2018-15-3-98-102.

Yudina, A.F., Dyachkova, O.N. (2010). Analysis of the versions of design-construction solutions of residential multi-storey buildings (on the example of Saint Petersburg). *Bulletin of Civil Engineers*, 2 (23), pp. 115–122.

Yudina, A.F. (2012). Advantages of monolithic building and some problems of its perfection. *Bulletin of Civil Engineers*, 1 (30), pp. 154–156.

Yudina, A.F., Ponomarev, M.Yu. (2016). Application of exposed concrete at erection of monolithic buildings. *Architecture and Engineering*, 1 (2), pp. 73–88. DOI: 10.23968/2500-0055-2016-1-2-73-88.