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Modern development trends in plastering units, stations, technological sets, and their control coordination systems

Abstract. Modern construction industry development is characterized by increased finishing operation productivity, quality, and resource efficiency requirements, with a significant share attributable to building mortar preparation, transportation, and application processes. Within total construction and installation work labour intensity structure, plastering operation share remains among the largest, necessitating further plastering process mechanization and automation. Plastering unit and station operation efficiency is largely determined by mixing and pumping unit design parameters, different mobility mortar supply stability, pipeline system pressure pulsation levels, and equipment operation mode coordination with building mixture rheological characteristics. Extensive morally and physically obsolete equipment use leads to technological process productivity reduction, energy consumption increase, and material application quality deterioration. At the same time, modern construction equipment development trends are associated with energy saving drive implementation, automated control system integration, process parameter digital monitoring technology application, robotic mortar application complex deployment, and mortar pump and mixing device design improvement. This necessitates existing plastering unit and station design feature system analysis and promising further development direction identification.

Keywords: plastering units, plastering stations, technological sets, building mortars, mixing devices, mortar pumps, pipeline mortar transportation, automated control systems, energy-efficient drives

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Introduction.

Analytical study of integrated plastering equipment design features and operational capabilities for further improvement prospects under contemporary technological challenges. To investigate domestic manufacture plastering unit technological set design feature improvement based on existing domestic and foreign manufacturer experience. The study applies analytical methods for design feature and technological capability evaluation depending on building mortar rheological models, as well as structural and technological unit and aggregate improvement approaches aimed at finishing operation efficiency increase depending on functional purpose. Proposed approaches for plastering unit qualitative capability evaluation according to classification features are presented. Proposed advanced design solutions for technological task solving of plastering unit operation efficiency increase include technological set control automation, energy saving drive link implementation, unit and mechanism controllability improvement, operator control comfort measures, design element improvement through modern technological solutions, and modern surface and mortar contact channel cleaning system application. Advanced technological and design solution implementation ensures finishing and shotcrete operation efficiency and allows mechanized building mixture preparation and transportation system productivity increase, process energy consumption reduction, and plastering unit technological parameter stability assurance. Mechatronic mechanism control system application in plastering units ensures technological operation quality improvement and execution time reduction. Self-cleaning system application also ensures post operation maintenance time reduction. Ergonomic and comfortable operator workplace cabin arrangement ensures full plastering unit or station technological process monitoring and control during finishing operations.

Problem statement.

Modern construction finishing-operation productivity growth requirements, coating-quality assurance demands, and resource-efficiency improvement tasks determine the necessity of plastering unit technological-set structural-functional coordination level increase. A significant construction installation labour-intensity share remains associated with building-mortar preparation, pipeline transportation, and surface-application processes, whose effectiveness depends on mixing-device geometric-parameter selection, pumping-unit delivery-stability characteristics, pipeline pressure-pulsation level reduction, and technological-process control-system adaptability to building-mixture rheological-property variation.

Existing plastering unit design-solution implementation practice demonstrates insufficient integrated technological-set subsystem coordination efficiency, limited energy-efficient drive-system application level, and inadequate automated technological-parameter monitoring capability. These factors cause mixture-supply irregularity increase, plaster-layer thickness deviation growth, process energy-consumption escalation, and finishing-operation productivity reduction under variable construction-site operating conditions.

At the same time, modern construction equipment digitalization trend development, robotic mortar-application system deployment expansion, and adaptive technological-process control-algorithm implementation necessity require integrated plastering unit structural-layout optimization and technological-set functional-interaction improvement based on mixing-pumping-application subsystem coordinated-operation principles. Therefore, plastering unit, station, and technological-set development-trend systematization and efficiency-increase direction identification considering building-mortar preparation, transportation, and application process interdependence represent a relevant scientific-engineering task.

Modern construction industry development is characterized by increasing requirements for productivity, quality, and resource efficiency of finishing operations. A significant share of construction and installation process labour intensity is associated with plastering operations, the efficiency of which is largely determined by the level of mechanization of building mortar preparation, transportation, and application processes. In this regard, the application of modern plastering units, stations, and technological sets ensuring integrated mechanization of finishing operations becomes especially important.

Plastering equipment operation efficiency is determined by mixing and pumping unit design parameters, different mobility mortar supply stability, pipeline system pressure pulsation levels, and equipment operating mode coordination with building mixture rheological characteristics. Insufficient mortar uniformity, supply irregularity, and high energy consumption lead to technological process productivity reduction and finishing operation quality deterioration.

In construction practice, a significant share of plastering units and stations is based on previous generation design solutions that do not fully meet modern requirements for mobility, versatility, energy efficiency, and technological process automation. At the same time, active implementation of new technical solutions is observed, including energy saving drives, improved mortar pumps, automated control systems, process parameter digital monitoring technologies, and robotic building mortar application complexes.

Under these conditions, the need arises for systematic analysis of modern plastering unit, station, and technological set development trends considering design, technological, and operational functioning factors, enabling identification of promising directions for mechanized finishing operation efficiency improvement in construction.

Plastering unit, station, and technological set design improvement issues are considered in a significant number of scientific and applied studies devoted to building mortar preparation, transportation, and application process efficiency improvement [1, 2, 6].

In studies devoted to next generation plastering station development, significant attention is given to receiving hopper, mixing device, and hydraulic drive mortar pump design improvement ensuring different mobility mortar supply stability and pipeline system pressure pulsation reduction. In particular, research conducted within the Poltava construction machinery scientific school substantiates the feasibility of rotary receiving hopper and differential hydraulic drive mortar pump application as effective means for plastering station productivity increase and operating condition improvement [1, 2].

Further development of plastering equipment design solutions is associated with building mixture mixing intensity increase, unit technological capability expansion, and energy consumption reduction, as reflected in fundamental research on integrated technological systems in construction [6]. Particular attention is given to coordination of mixing and pumping unit operating parameters with building mortar rheological characteristics.

Analysis of modern foreign manufacture plastering unit designs shows that leading construction equipment manufacturers focus on universal modular installation development with high efficiency pumping systems, automated drives, and electronic technological process control systems [3–5, 7, 10, 11]. Such units ensure stable mixture supply over long distances, operation capability with materials of different consistency, and increased operational reliability level.

At the same time, considerable attention in modern research is given to building mixture transportation process modelling using pumping equipment. The obtained results allow evaluation of pump design parameter and medium property influence on material supply characteristics and pipeline system pressure losses, which is important for plastering unit operation efficiency improvement within technological set structures [8, 9].

At the same time, literature source analysis shows that integrated generalization issues of modern plastering unit, station, and technological set development trends considering construction production automation, digitalization, and robotization tendencies remain insufficiently covered, which determines the need for further research in this direction.

The purpose of this work is analysis of modern plastering unit, station, and technological set development trends based on domestic and foreign research and design solution experience generalization, as well as identification of promising directions for building mortar preparation, transportation, and application process efficiency improvement through mixing and pumping unit improvement, energy efficient drive implementation, and automated control system integration.

Figure 1 − Plastering unit IMER MIX 60 (IMER Int.)

Main part.

Modern plastering units (Fig. 1–3) and stations (Fig. 4) should be considered not as separate local action machines but as integrated technological systems whose efficiency is determined by coordination of building mortar receiving, mixing, transportation, and application processes. This approach corresponds to modern construction machinery development trends, according to which equipment technical level improvement is ensured not only by individual unit design improvement but by comprehensive optimization of technological system functioning parameters as a whole.

a) b)

c) d)

Figure 2 − Plastering unit of a German company PUTZMIESTER: a) with screw pump b); with a rotor–stator (screw-type, auger-type) mortar pump c) P 715 TD P 718 with a two-piston mortar pump TD; d) P 13 EMR with single piston mortar pump

Functionally, a plastering technological set includes a receiving hopper, mixing device, pumping unit, transport pipeline, and mortar application working element. Interaction of these components forms a unified dynamic process of mortar mixture property transformation from receiving stage to formation of a plaster layer of specified thickness on building structure surfaces. Therefore, unit operation efficiency is determined not only by individual mechanism productivity but also by their mutual coordination.

Figure 3 − Plastering units UNI 30 manufactured by Turbosol

Figure 4 − Plastering station СШ-4Г

For quantitative evaluation of plastering unit technical level, an integral technological set operation efficiency criterion is proposed that considers mixture supply productivity, mixture uniformity degree, transportation stability, pipeline pressure pulsation level, and specific process energy consumption. Such a criterion allows consideration of mortar preparation and supply processes as a unified controlled system with interdependent parameters.

From an engineering point of view, plastering unit operation should be represented as a structural interaction diagram of mixing, pumping supply, and mortar application subsystems. In this scheme, the mixing unit ensures material structure uniformity, the pumping unit provides transportation with specified supply parameters, and the application working element determines plaster layer formation quality.

One of the main characteristics of mixing process efficiency is the building mixture uniformity coefficient, which depends on mixer working element geometric parameters, their operating kinematic modes, and medium rheological properties. During mixing, intensive mixture component redistribution occurs, accompanied by simultaneous structure formation and segregation processes. Consideration of these factors allows description of mixture uniformity change as a function of working element rotation speed and mixer design parameters, creating the possibility for optimal operating mode determination.

An important stage of plastering unit operation is building mortar transportation through the pipeline system. Hydrodynamic characteristics of this process are determined by pipeline length and diameter, mixture flow regime, its viscoplastic properties, and pumping unit design parameters.

It is known that building mortars belong to the class of structured media with yield shear stress presence; therefore, transportation pressure losses strongly depend on mixture rheological characteristics and interaction conditions with pipeline inner surface.

Particular importance is given to building mortar supply stability, which determines plaster layer formation uniformity and finishing operation efficiency. Supply pulsations typical of piston pumps lead to nonuniform material distribution on surfaces and increased mixture consumption. Therefore, one of the promising directions of modern plastering unit development is multipiston pumping scheme application, pressure compensator implementation, and adaptive mortar supply control system integration.

Plaster layer formation quality is determined by interaction between material flow rate, working element movement speed, and application jet width. Coordination of these parameters ensures layer thickness uniformity and material loss reduction during finishing operations.

At the same time, synchronization of pumping equipment operating modes and application working element operation plays an important role, which is especially relevant for automated and robotic plastering systems.

Plastering unit energy efficiency is determined by total power consumption for mixing mechanism drives, pumping equipment, and auxiliary control systems. Specific energy consumption reduction is achieved through drive kinematic scheme optimization, variable frequency electric motor application, and unit operating mode coordination with building mixture rheological characteristics. In modern plastering station designs, this is ensured through electrohydraulic drive implementation with automatic load regulation.

An important direction for plastering unit operation efficiency improvement is digital technological process parameter monitoring system application. Pressure, flow rate, temperature, and mixture moisture sensor use enable continuous equipment operating mode monitoring and prompt material supply parameter adjustment. This creates prerequisites for adaptive control algorithm implementation in building mortar preparation and transportation processes.

Integration of plastering units into construction site digital environment ensures coordination of their operation with other technological complex elements. Building information modelling technologies enable automatic equipment operating mode adjustment depending on surface geometric parameters, work volumes, and technological operation conditions. In the future, this creates prerequisites for fully automated finishing operation technological system development.

Thus, the proposed generalized mathematical model of plastering unit operation allows their consideration as integrated technological systems with interdependent building mortar mixing, transportation, and application parameters.

This provides the possibility of systematic substantiation of mixing device, pumping unit, transport system, and automated control system design improvement directions, corresponding to modern construction equipment development trends and creating prerequisites for mechanized finishing operation efficiency improvement.

Modern plastering units, stations, and technological sets should be considered as integrated multistage technological systems in which building mortar receiving, mixing, transportation, and application processes are interconnected and interdependent. In this formulation, equipment operation efficiency is determined not by individual unit design parameters but by their coordinated operation within a unified technological cycle.

For quantitative description of plastering unit operation, an integral technological set efficiency criterion is proposed

$$\Phi = \frac{Q\,K_h\,K_s\,K_a}{E_{sp}\,K_p} \qquad (1)$$

where Q – building mortar supply productivity, m³/s;

K_h – mixture homogeneity coefficient;

K_s – feed stability coefficient;

K_a – adaptability factor of the control system;

E_{sp} – specific energy consumption of the process, J/m³;

K_p – supply pulsation coefficient.

The proposed criterion enables evaluation of plastering unit technical level considering productivity, mixing quality, mortar transportation uniformity, and operation energy efficiency.

One of the determining factors of plastering unit operation efficiency is building mixture uniformity degree after mixing. Mixture uniformity coefficient variation depends on mixer kinematic parameters and working element geometry and can be represented in the form of a differential equation

$$\frac{dK_h}{dt} = a_1\omega^{\alpha}\beta^{\gamma}(1-K_h) - a_2\psi K_h \tag{2}$$

where ω – mixer working element angular velocity, rad/s;

β – generalized mixing device geometry parameter;

ψ – mixture structural instability parameter;

a_1, a_2 – empirical coefficients;

α, γ – power exponents.

In steady state conditions, the uniformity coefficient is determined by the following relationship

$$K_h^* = \frac{a_1\omega^{\alpha}\beta^{\gamma}}{a_1\omega^{\alpha}\beta^{\gamma} + a_2\psi} \tag{3}$$

The obtained relationship enables evaluation of mixing element geometric parameter and operating mode influence on mortar preparation quality.

Pumping unit productivity is determined by delivery working volume, operating cycle frequency, and material losses in the transportation system

$$Q = \eta_v V_0 n - Q_l \tag{4}$$

where η_v – pump volumetric efficiency coefficient;

V_0 – delivery volume per cycle, m³;

n – working cycle frequency;

Q_l – delivery losses.

Pressure drop in the pipeline system is determined by the sum of friction losses, local losses, and the hydrostatic component

$$\Delta p = \Delta p_f + \Delta p_l + \Delta p_h\,. \tag{5}$$

For building mortars as viscoplastic media, friction pressure losses can be expressed by the following relationship

$$\Delta p_f = \frac{4L}{D}\tau_w \tag{6}$$

where L – pipeline length;

D – pipeline diameter, mm;

τ_w – pipeline wall shear stress.

Plaster coating formation quality is determined by the relationship between material flow rate, working element movement speed, and application jet width

$$h = \frac{\eta_n Q}{b v_m}\,, \tag{7}$$

where h – plaster layer thickness, mm;

η_n – material deposition coefficient on the surface;

b – application jet width;

v_m – working element movement speed, m/s.

Deviation of layer thickness from the specified value is determined by the following relationship

$$\delta_h = \left|\frac{h - h_{opt}}{h_{opt}}\right| \tag{8}$$

Based on this, an application quality coefficient is introduced

$$K_n = 1 - \delta_h \tag{9}$$

For evaluation of automated technological process control efficiency, an adaptability coefficient is introduced

$$K_a = \frac{1}{1+\varepsilon} \tag{10}$$

where

$$\varepsilon = w_1\left|\frac{Q - Q_{set}}{Q_{set}}\right| + w_2\left|\frac{p - p_{set}}{p_{set}}\right| + w_3\left|\frac{h - h_{opt}}{h_{opt}}\right| \tag{11}$$

Here w_1, w_2, w_3 – weighting coefficients of control parameter significance.

Thus, the proposed generalized mathematical model enables consideration of plastering units, stations, and technological sets as a unified integrated system with interdependent operation parameters, creating a theoretical basis for substantiation of modern development directions aimed at productivity increase, material supply stability improvement, coating application quality improvement, and technological process energy efficiency increase.

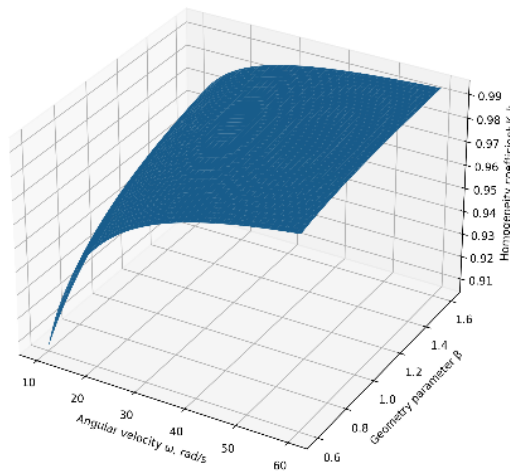

Figure 5 – Surface of building mixture uniformity coefficient variation depending on mixer working element angular velocity and generalized mixing device geometric parameter

From the constructed surface (Fig. 5), it can be seen that with increasing working element angular velocity and improvement of mixer geometric parameter, mixture uniformity coefficient increases. At the same time, in the region of high parameter values, gradual approach to a limiting uniformity level is observed, indicating the presence of a mixing effect saturation zone.

Therefore, mixing unit efficiency improvement should be ensured not only by working element rotation speed increase but also by rationalization of working element geometry.

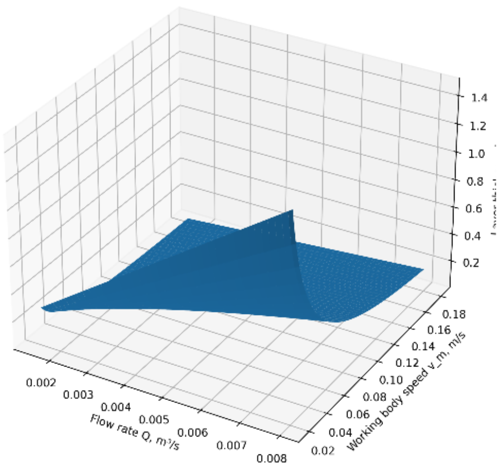

Figure 6 – Surface of plaster layer thickness variation depending on building mortar supply productivity and application working element movement speed

Analysis of Fig. 6 shows that the constructed surface indicates plaster layer thickness increase with mortar supply productivity increase and decrease with working element movement speed increase.

This confirms the need for coordination of pumping supply parameters and application mode to ensure stable layer thickness. Thus, plaster coating quality is determined not only by material flow rate but also by application working element motion kinematics.

Conclusions.

A generalization of modern plastering unit, station, and technological set development trends for mechanized finishing operation execution has been carried out, allowing formation of a systematic understanding of the relationship between equipment design parameters and building mortar preparation, transportation, and application process efficiency.

It is shown that plastering unit operation efficiency is determined by coordination of mixing device, pumping unit, transport system, and mortar application working element parameters, and equipment technical level improvement should be carried out based on an integral efficiency criterion considering material supply productivity, mixture uniformity degree, transportation stability, pressure pulsation level, and specific process energy consumption.

It is established that one of the priority directions of plastering unit improvement is mixing unit efficiency increase through optimization of working element geometric parameters and rational selection of their operating kinematic modes, ensuring building mixture uniformity increase and rheological characteristic stability during transportation through pipeline systems.

It is substantiated that building mortar supply uniformity improvement is achieved through advanced pumping scheme application, pressure pulsation reduction, and pumping equipment parameter coordination with pipeline system characteristics, ensuring plaster layer formation quality improvement and material overconsumption reduction.

It is shown that a promising direction of plastering station development is energy efficient drive implementation, automated technological process control system integration, and material supply parameter digital monitoring system application, creating prerequisites for adaptive equipment operating mode implementation depending on building mixture properties and operation conditions.

It is established that further technological set operation efficiency improvement for plastering work execution is associated with plastering unit integration into construction production digital environment, robotic material application system use, and coordination of their operating parameters with building object information models.

The proposed generalized mathematical model of plastering unit operation enables evaluation of design and operating parameter influence on productivity, coating application quality, and process energy efficiency, creating a theoretical basis for further substantiation of mixing device, pumping unit, and automated control system improvement directions for construction machine technological sets.

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Сучасні напрямки розвитку штукатурних агрегатів, станцій, технологічних комплектів та систем погодження керування ними

Аннотація. Сучасний розвиток будівельної галузі характеризується підвищеними вимогами до продуктивності, якості та ресурсоефективності виконання опоряджувальних робіт, значна частка яких припадає на процеси приготування, транспортування та нанесення будівельних розчинів. У структурі загальної трудомісткості будівельно-монтажних робіт частка штукатурних операцій залишається однією з найбільших, що обумовлює необхідність їх подальшої механізації та автоматизації. Ефективність функціонування штукатурних агрегатів і станцій значною мірою визначається конструктивними параметрами змішувальних і насосних вузлів, стабільністю подачі розчинів різної рухомості, рівнем пульсацій тиску в трубопровідних системах, а також узгодженістю режимів роботи обладнання з реологічними характеристиками будівельних сумішей. Використання значної кількості морально та фізично застарілого обладнання призводить до зниження продуктивності технологічних процесів, підвищення енергоємності та погіршення якості нанесення матеріалу. Водночас сучасні тенденції розвитку будівельної техніки пов'язані з упровадженням енергоощадних приводів, автоматизованих систем керування, цифрових технологій моніторингу параметрів процесу, роботизованих комплексів нанесення розчинів, а також удосконаленням конструкцій розчинонасосів і змішувальних пристроїв. Це зумовлює необхідність системного аналізу конструктивних особливостей існуючих штукатурних агрегатів і станцій та визначення перспективних напрямків їх подальшого розвитку. Аналітичні дослідження конструктивних особливостей комплексного штукатурного обладнання та експлуатаційних можливостей за для перспективи вдосконалення перед викликами часу.
Метою статті є дослідження питання вдосконалення конструктивних особливостей технологічних комплектів штукатурних агрегатів вітчизняного виробництва на основі існуючого досвіду вітчизняних і закордонних виробників. Запропоновані підходи оцінки якісних можливостей за класифікаційними ознаками штукатурних агрегатів. Запропоновані конструктивні новітні рішення вирішення технологічних задач підвищення ефективності роботи штукатурних агрегатів, а саме: автоматизацією управління технологічними комплектами, енергозаощадливими приводними ланками, керованістю вузлами і механізмами, заходами комфорту керування оператором, вдосконалення конструктивних елементів через сучасні технологічні рішення, сучасними системами очистки поверхонь та каналів контакту з розчинним середовищем. Впровадження новітніх технологічних і конструктивних рішень забезпечить ефективність проведення оздоблювальних та торкрет-робіт дозволяє: підвищити продуктивність механізованих систем приготування і транспортування будівельних сумішей, знизити енергоємність процесів та забезпечити стабільність технологічних параметрів роботи штукатурних агрегатів. Застосування мехатронних систем керування механізмами штукатурних агрегатів забезпечить якість технологічних операцій та скоротить час їх проведення. Також застосування систем самоочистки забезпечить скорочення часу на післяопераційне обслуговування. Оформлення ергономічного та комфортного робочого місця (кабіни) оператора, яке забезпечить повний контроль і управління технологічними процесами штукатурного агрегату чи станції під час оздоблювальних робіт.

Ключові слова: штукатурні агрегати, штукатурні станції, технологічні комплекти, будівельні розчини, змішувальні пристрої, розчинонасоси, трубопровідний транспорт розчинів, автоматизовані системи керування, енергоефективні приводи, математичне моделювання технологічних процесів

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