UDC 691.32:621.869
DOI: 10.15587/2706-5448.2024.319827

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OPTIMIZATION OF THE CONCRETE PRODUCTION PROCESS IN TERMS OF ENERGY CONSUMPTION

The object of study is the power supply system of a concrete mixing plant. The research made it possible to identify and eliminate the shortcomings of the existing power supply system in order to increase its energy efficiency and productivity. A new concept has been proposed, which provides for an individual arrangement of bins with isolated conveyors for each of them.

The study revealed a number of significant advantages of the proposed system, namely:

– separate conveyors for each hopper allow to optimize the routes of material movement, avoid unnecessary movements and reduce the load on the drives;

– the use of modern electric motors with high efficiency and other energy-saving components can further reduce energy consumption;

– due to the independent operation of each hopper, it is possible to load different materials in parallel, which reduces the time required to prepare a new portion of the concrete mixture;

– the absence of a common hopper reduces the risk of congestion and obstacles that can lead to equipment downtime;

– due to the independence of each hopper, different types of concrete mixtures can be prepared simultaneously.

However, there are some potential disadvantages and risks to consider before implementing a new system, including:

– the implementation of a new system may require significant investment in new equipment and installation;

– the number of system components increases, which may complicate its maintenance and repair;

– the efficient operation of the new system requires the development of special software and automation systems.

Despite some drawbacks, the introduction of a power supply system for a concrete mixing plant is a promising direction for the development of the machine-building and construction industry. The results of the study indicate the high efficiency of this technology and its economic feasibility in the long term.

Keywords: *power supply systems, concrete mixing plant, hopper, conveyor, concrete mixture, automation system.*

Received: 04.10.2024
Received in revised form: 29.11.2024
Accepted: 20.12.2024
Published: 31.12.2024

How to cite
Levchenko, O., Korobko, B. (2024). Optimization of the concrete production process in terms of energy consumption. Technology Audit and Production Reserves, 6 (1 (80)), 11–15. https://doi.org/10.15587/2706-5448.2024.319827

1. Introduction

The constant growth of the global construction sector and the strengthening of environmental requirements for the development of energy-saving technologies are becoming an extremely urgent and important task [1]. One of the key areas of improvement is the supply systems of concrete mixing plants, which play an important role in the production of concrete for construction [2].

Concrete mix is widely used in construction in the manufacture of various monolithic and prefabricated structures. This material is a homogeneous mass consisting of a binder (cement), coarse and fine aggregates (crushed stone, sand), water, as well as various additives that improve the properties of concrete. In each individual case, a careful calculation of the components is carried out, which must be observed when drawing up the proportions [3, 4].

The process of producing concrete and mortar mixtures is a series of sequential mechanized and, mainly, automated operations:

– warehousing and storage of inert materials and cement;
– batching of sand, crushed stone, water, chemical additives and pigments;
– mixing of components;
– transporting concrete to its destination [5].

The constant increase in requirements for concrete quality and production efficiency, along with the need to reduce energy consumption and emissions of harmful substances into the air, requires revolutionary changes in this area [6–9]. Therefore, *the aim of this scientific research* is to develop a new energy-saving design of the concrete mixing plant power supply system, aimed at improving their efficiency and reducing the negative impact on the environment.

2. Materials and Methods

When studying the power supply system of a concrete mixing plant (CMP), the design documentation for the concrete mixing plant, and operating instructions. Data on electricity consumption by various components of the power supply system, data on compressed air consumption, and statistical data on the plant's productivity, frequency

 ISSN-L 2664-9969; E-ISSN 2706-5448

of failures and downtime were used. The results of laboratory analyses of concrete mixtures were also used to assess the impact of changes in the power supply system on product quality.

A detailed analysis of the design features of the existing power supply system was also conducted, and bottlenecks and potential problems were identified.

3. Results and Discussion

The technological process of producing concrete mixtures and mortars at the modern level is a chain of interconnected mechanized and, in most cases, automated operations:
- warehouse processing of materials, including loading and unloading and stacking operations;
- transportation of components to the output hoppers of the mixing unit;
- batching of components;
- preparation (mixing) of the mixture;
- unloading of the finished mixture.

With the segmented production technology, mixing of the dosed components is carried out on the way of transport or in mixing plants located at the places of laying concrete. Fig. 1 shows the schematic diagram of the concrete mixing plant.

Depending on the purpose, capacity and characteristics of the consumer facilities, there are stationary and quickly relocated concrete plants, quickly relocated prefabricated plants and mobile mixing plants.

Stationary continuous plants produce ready-mix concrete (mortar) for various consumers or for a reinforced concrete prefabricated structures plant.

Quickly relocated plants are built for the construction of specific facilities, taking into account their operation for several years. For better use, such plants should be able to be quickly relocated to other facilities without large costs for installation and dismantling of equipment and stationary structures.

Mobile concrete and mortar mixing plants are units mounted on trailers or consist of blocks transported by vehicles. These plants are designed to service concentrated facilities.

The plant or installation includes:
- aggregate and cement warehouses with stacking machines and lifting and conveying equipment for feeding them to the mixing department;
- a mixing department with batching equipment, feed hoppers, mixing machines and devices for receiving the finished mixture and delivering it to the consumer.

Concrete mixing and mortar mixing plants and installations are classified according to the following features:
- operating mode – periodic and continuous;
- layout scheme – high-altitude and step-by-step.

With the high-altitude scheme, the components are lifted to their full height once, after which they move only under the influence of gravity throughout the entire technological cycle.

With the two-stage layout scheme, the concrete mixture is sequentially lifted first into the feed hoppers, then, after batching, into the mixing machine.

Fig. 2 shows a concrete mixing plant with four gravity concrete mixers arranged in a high-altitude layout. The volume of the finished mix of each concrete mixer is 1600 liters.

Aggregates are fed from the warehouses by a belt conveyor 11 through a rotary funnel 10 into the compartments of the charge hoppers. Cement is fed by pneumatic transport into the cyclone 8, from which it is sent through an air chute to the hopper 7. Final air purification is carried out in a bag filter 9. From the charge hoppers, cement is fed through a batcher 12, and aggregates through a batcher 13 into a collection hopper 4 with a rotary funnel and are poured into concrete mixers 2. Water through a batcher 6 and liquid additives through a batcher 5 through a pipeline enter directly into the rotary funnel.

The finished mixture from the concrete mixers is unloaded into the distribution hoppers 1. The equipment is controlled from a remote control 14 placed in the batching compartment.

Tower-type concrete mixing units are similar in layout to the concrete plants under consideration. Fig. 3 shows a technological scheme for preparing mortar and concrete on an automated construction unit in which turbulent mixers are used. Cement from silo 1 is fed by an auger 2, an elevator 31 and an auger 30 into a hopper 29. From the hopper, cement is fed by a feeder 14 into a batcher 15, from which it enters a mixer 9. Aggregates from warehouses 3 are fed by a conveyor 4 to a crusher 6. Screened sand is fed by an elevator 7 into a drum sand sifter 24 and then into a hopper 25. Large inclusions from a crusher 6 are fed by a shaft lift 5 into a waste hopper 8. Crushed stone from the warehouse is transported by the same chain of machines and transport 26 into a hopper 27. From the hoppers, sand is fed by feeders 21 and 23 into a batcher 22 and then into a mixer. Water is supplied to the mixer from tank 28 through valve 17 and batcher 16. Lime from tank 13 and additives from additive tanks 12 and 10 are supplied by pumps 11 to the corresponding dispensers 18, 19 and 20, from which they merge into the mixer.

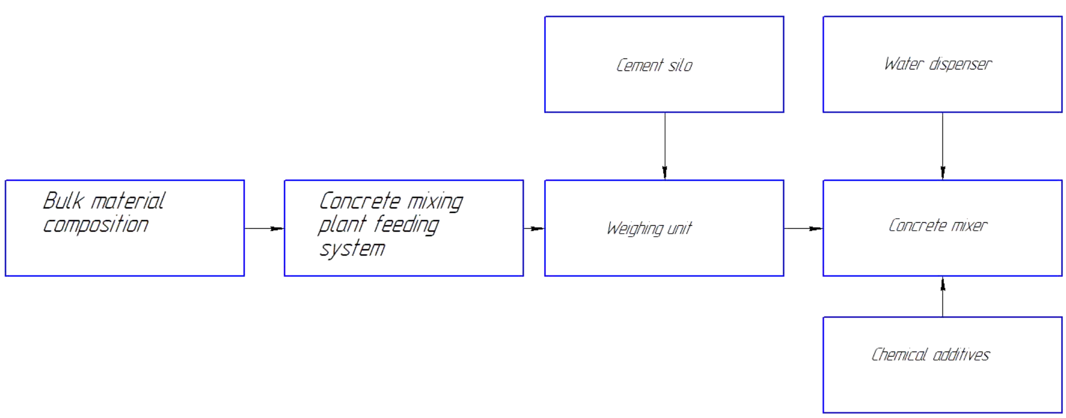

Fig. 1. Schematic diagram of a concrete mixing plant

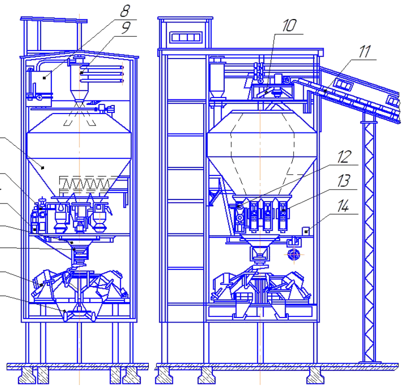

Fig. 2. Scheme of a concrete mixing unit with four concrete mixing units [10]: 1 – distribution hoppers; 2 – concrete mixer; 3 – gate; 4 – collection hopper; 5, 6, 12, 13 – batchers; 7 – hopper; 8 – cyclone; 9 – bag filter; 10 – rotary funnel; 11 – belt conveyor; 14 – remote control

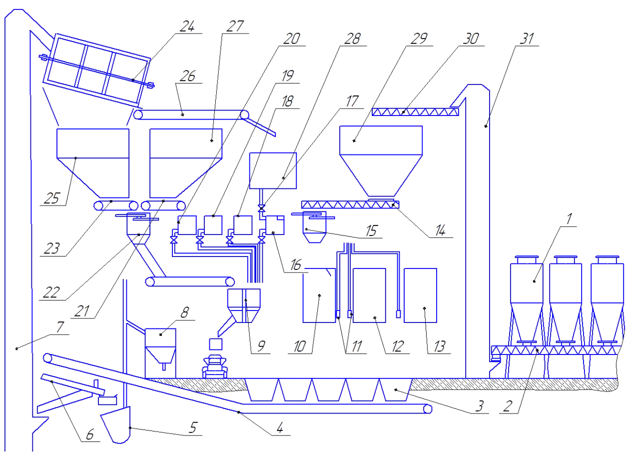

Fig. 3. Technological scheme of a concrete mixing unit with a turbulent mixer [10]: 1 – silo; 2, 30 – auger; 3 – material warehouse; 4, 26 – conveyor; 5 – shaft lift; 6 – crusher; 7, 31 – elevator; 8 – waste hopper; 9 – mixer; 10, 12 – additive tank; 11 – pump; 13 – lime tank; 14, 21, 23 – feeder; 15, 16, 18, 19, 20, 22 – batcher; 17 – valve; 24 – sand sifter; 25, 27, 29 – hopper; 28 – water tank

Fig. 4 shows a diagram of a two-stage continuous concrete batching plant (type SB-75), with a capacity of 30 m^3/h, designed for preparing concrete on open sites during the construction of roads, airfields, etc.

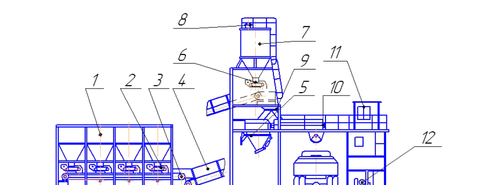

Fig. 4. Scheme of a continuous concrete batching plant [10]: 1 – hopper; 2 – continuous batching unit; 3 – conveyor; 4 – inclined conveyor; 5 – cyclic batching unit; 6 – cement batching unit; 7 – silo (cement hopper); 8 – filter; 9 – collection hopper; 10 – continuous mixer; 11 – control unit; 12 – batching pump

The plant consists of three main units: a batching unit for aggregates, a mixing compartment with a cement hopper and a control unit. Aggregates from hopper 1 through continuous batching units 2 are fed via conveyor 3 to an inclined conveyor 4 and a collection hopper 9. Cement from cement trucks is sent to a hopper 7 equipped with a filter 8, and then to a collecting hopper by a batching unit 6. The plant can produce a ready-made mixture using a continuous mixer 10, where water is supplied by a batching pump 12 from a tank located under the control unit 11, or load separately dosed dry components and water into a concrete mixer truck. The installation has a cyclic batching unit 5 mounted on a sliding frame.

The batching unit of a plant or installation is one of the main units, it can be called a bulk materials supply system. It consists of a hopper for temporary storage of the material, batchers and a belt conveyor.

Bulk materials hoppers are classified as the main type of auxiliary equipment. The purpose of the hoppers is to create an operational supply of materials for uninterrupted production.

Consumption hoppers are designed so that they can contain the materials necessary for preparing the concrete mix for 2–4 hours of operation. Usually, the supply of materials in the consumption hoppers is taken equal: for aggregates – for 1–2 hours, for cement – 2–3 hours. The number of hoppers or their compartments is determined by the development of the production process scheme and depends on the range of mixtures, line productivity, choice of installation layout (single-, two-stage and others). Usually, their number is at least two for each type of material. Consumption hoppers are located above the batchers and are equipped with shutters on the outlet openings.

The design properties of concrete mixtures and concretes are ensured by batching (measuring) their components with the required accuracy. This operation is carried out using batchers. Batchers are volumetric and weight, periodic and continuous, with manual, semi-automatic and automatic control. In modern conditions, automatic batchers of periodic action are used in most cases.

A weight or volume-weight batcher of periodic action consists of a measuring device (a rectangular or more often cylindrical vessel with a pyramidal or conical lower part), a shutter and a weighing mechanism (device). For many years, weight batchers with a lever weighing mechanism were used in concrete mixing plants, which was unreliable, rather complex and poorly amenable to automation. Now, weight batchers on strain gauges are widely used, the design of which is very simple: the measuring device is installed on strain gauges or suspended from strain gauges. The most commonly used are strain gauges with a resistance that varies depending on the deformations caused by gravity. The electrical signal is processed by a controller.

The use of strain gauges has made it possible to sequentially dose several materials with one butcher, for example, fine and coarse aggregates, different fractions of coarse aggregate, since they provide the necessary accuracy within the weighing range. In addition, it is possible to carry out weight batching of bulk materials using weighing conveyors-butchers.

The last component of the system is a belt conveyor that feeds the dosed material to the mixer.

The power system in Fig. 5 consists of a belt conveyor that is attached to the hoppers using strain gauges and is a weighing platform. Between the conveyor and the hoppers, measuring devices for sand and gravel are installed, the volume of which is equal to the required portion for one batch of concrete. The material is loaded into the hoppers, then this material is dosed for concrete preparation. The operator gives a command and the hopper gates open one by one, through a pneumatic drive, the material enters the measuring device and when the specified weight is reached, the gate closes. The measuring device and the gate are quite large elements, this is done in order to reduce the hanging of materials in the hopper and speed up batching. Then the conveyor is turned on and transports the material to the mixer. The conveyor drive must be powerful, since the measuring devices contain material for one batch. For example, if the mixer has a working volume of 0.5 m^3, the mass of bulk materials will be about 1000 kg. The conveyor will turn off when there is no material left in the measuring devices and on the belt. The disadvantages of this equipment are a large gate, which significantly affects the error when weighing the material, a powerful and energy-consuming conveyor. Also, during operation of the equipment, vibration occurs, which negatively affects the load cells and creates a large error in weighing and premature failure, as well as the need to free the conveyor belt from materials. This significantly affects the productivity of the installation.

It is proposed to change the design and schematic diagram of the feeding system so that each hopper is located separately from each other and has its own conveyor (Fig. 6). Weighing will take place in a separate measuring device, which is installed on strain gauges or a weighing platform. The feeder hopper will be a measuring device in which there are no gates, and a gate valve is installed in the discharge opening to regulate the supply of materials.

This technology is of great *practical importance*, because during operation, vibration will not affect the weighing system, since it is located separately from the working units. There are no gates and gauges in the feeders, which greatly simplifies the design and reduces the height of material loading with the same volume of hoppers. Although there will be several conveyors, they will be smaller and less powerful. It will be possible, if necessary, to add material in any sequence and quantity, and there will always be material on the belt, which will allow instant dosing and significantly increase the productivity of the plant. With this layout, the system will be more compact, and when organizing a canopy to protect against precipitation, there will be a place for temporary storage of materials. No less important is the fact that cement can be dosed using a single weighing system.

Despite its value, there are *certain limitations*, because the concrete production process depends on a large number of variables, such as the type of cement, the type of aggregates, the amount of water, additives, mixing and hardening conditions. The interaction of these factors is extremely complex and not always linear. Changing one parameter can lead to unpredictable consequences for the properties of concrete. This makes it difficult to create simple models that would accurately describe all processes.

Martial law also had an impact on the results of the study, because the difficulty lies in importing the necessary equipment and reagents.

In the future, it is desirable to compare the energy efficiency of this installation with similar installations at other enterprises, as well as take into account the interrelationship of various factors, such as technological processes, equipment, energy sources and production organization.

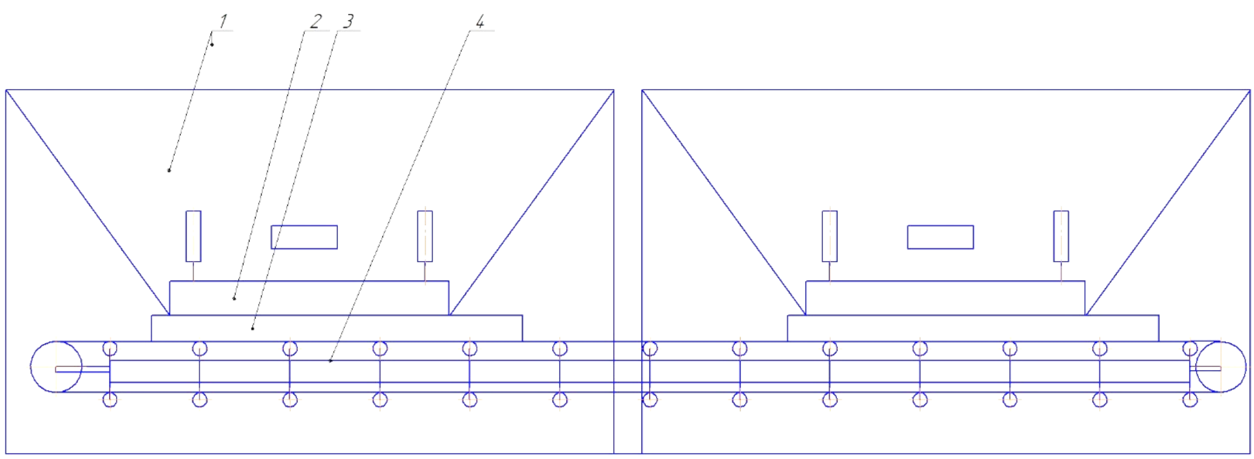

Fig. 5. Concrete mixing plant supply system: 1 – receiving hopper; 2 – pneumatic gate; 3 – measuring device; 4 – conveyor

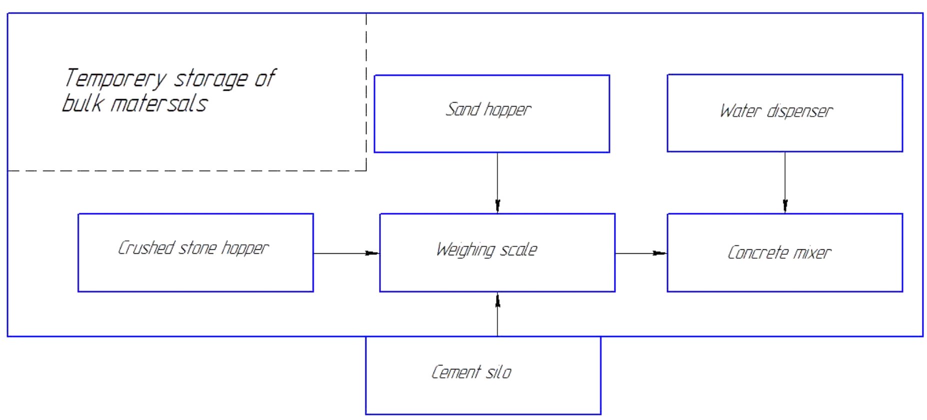

Fig. 6. Schematic diagram of a concrete mixing plant

4. Conclusions

The research results of the energy efficiency of the concrete mixing plant design led to an important conclusion regarding the need for changes in the schematic diagram of the power supply system. The proposed changes involve the location of each hopper separately from each other, each of which will have its own conveyor.

This new schematic diagram of the power supply system will help increase the energy efficiency of the installation in several ways:

– the isolated location of the hoppers and the use of separate conveyors will optimize the operation of the power supply system, avoiding unnecessary energy consumption for transporting materials;

– each hopper will be able to operate independently, which will help increase productivity and reduce the time for changing the loaded material;

– the introduction of separate conveyors for each hopper will reduce the risk of congestion and interference in the power supply system, which will help avoid wasting time and energy on solving such problems.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The research was performed without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Worrell, E., Galitsky, C. (2008). Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making. *An ENERGY STAR Guide for Energy and Plant Managers. Office of Scientific and Technical Information (OSTI)*. https://doi.org/10.2172/927882
2. Cantini, A., Leoni, L., De Carlo, F., Salvio, M., Martini, C., Martini, F. (2021). Technological Energy Efficiency Improvements in Cement Industries. *Sustainability, 13 (7),* 3810. https://doi.org/10.3390/su13073810
3. Liu, H., Zhao, Q. (2023). Review on Energy Conservation of Construction Machinery for Pumping Concrete. *Processes, 11 (3),* 842. https://doi.org/10.3390/pr11030842
4. Hnatov, A., Patlins, A., Arhun, S., Kunicina, N., Hnatova, H., Ulianets, O., Romanovs, A. (2020). Development of an unified energy-efficient system for urban transport. *2020 6th IEEE International Energy Conference (ENERGYCon),* 248–253. https://doi.org/10.1109/energycon48941.2020.9236606
5. Sadeghian, O., Moradzadeh, A., Mohammadi-Ivatloo, B., Abapour, M., Anvari-Moghaddam, A., Shiun Lim, J., Garcia Marquez, F. P. (2021). A comprehensive review on energy saving options and saving potential in low voltage electricity distribution networks: Building and public lighting. *Sustainable Cities and Society, 72,* 103064. https://doi.org/10.1016/j.scs.2021.103064
6. Xiang, Q., Pan, H., Ma, X., Yang, M., Lyu, Y., Zhang, X. et al. (2024). Impacts of energy-saving and emission-reduction on sustainability of cement production. *Renewable and Sustainable Energy Reviews, 191,* 114089. https://doi.org/10.1016/j.rser.2023.114089
7. Radchenko, A., Radchenko, M., Mikielewicz, D., Pavlenko, A., Radchenko, R., Forduy, S. (2022). Energy Saving in Trigeneration Plant for Food Industries. *Energies, 15 (3),* 1163. https://doi.org/10.3390/en15031163
8. Lee, D., Lin, C. (2024). Universal artificial intelligence workflow for factory energy saving: Ten case studies. *Journal of Cleaner Production, 468,* 143049. https://doi.org/10.1016/j.jclepro.2024.143049
9. Lai, X., Dai, M., Rameezdeen, R. (2020). Energy saving based lighting system optimization and smart control solutions for rail transportation: Evidence from China. *Results in Engineering, 5,* 100096. https://doi.org/10.1016/j.rineng.2020.100096
10. Nazarenko, I. I., Tumanska, O. V. (2004). *Mashyny i ustatkuvannya pidpryyemstv budivelnykh materialiv: konstruktsiyi ta osnovy ekspluatatsiyi.* Kyiv: Vyshcha shkola, 590.

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