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Research paper

Wet Shotcrete Process Using a New Set of Small-Sized Equipment for Concreting Formless Computer Simulation

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Abstract

The article discusses the new all-purpose small equipment process usage. On example of the proposed equipment process analysis was maiden computer simulation. Basic machine determining dependences unevenness values are given - concrete pump hose and the value of its reliable operation. Full automation of wet shotcrete working process controlling algorithm developed.

Keywords: *Wet process shotcrete, breadboard, new equipment, computer simulation, the combination of operations over time, a complete 3D printing, basic machine, the safety factor of the concrete pump, formless concreting.*

1. Introduction

1.1. Overview

Sprayed concrete or shotcrete is known for more than eighty years. The first works with shotcrete were performed in the United States in Allentown in 1907 the company «CEMENT-GUN».
The firm "Kumagai-gumi" (Japan) "wet" shotcrete method with special dry dedusting additive used in underground construction [1].
The firm "Theisen" (Japan) developed a high (6 ... 12 m3/ h) set for automated preparation and application of shotcrete mixture nozzle remotely controlled on the boom of the excavator.
Used sprayed concrete casting and also in Belgium Norway [1]. The main feature of "Norwegian method" - fastening anchors production and dispersion-reinforced shotcrete, applied "wet" method. The company «BEKAERT» (Belgium) has developed a technology to produce concrete reinforced with steel fiber for use in the construction of various structures, which are increased requirements for impact resistance.

1.2. Relevance

Currently, the use of wet shotcrete process compared with the dry process is dominant because of its advantages. The advantages of the wet shotcrete process are:
- bounce not exceed 5-10% using suitable equipment;
- low content of dust in the working environment;
- improved adhesion;
- increased performance with reduced energy consumption;
- possibility to use a steel sanitary ware and fibers, various additives for improving workflow efficiency.

Application shotcrete allows mechanizing and automating the production of works, to carry out concreting formless.
Noteworthy breadboard small equipment intended for concreting the monolithic concrete coatings or for the production of reinforced concrete structures and products of complex geometric shapes at the construction site by a wet shotcrete with formless concreting.
An example of such a kit can serve as a set of equipment shown in Figure 1.

1.3. The aim

To develop a three-dimensional model of a new process kit compact equipment to fully perform the operating cycle when aligned in time of all processing steps starting from preparation of building mixtures and solutions for various purposes prior to spraying by a wet shotcrete on objects constructed or made of reinforced concrete structures and products in terms of construction sites using the method formless concreting.

2. Main Body

The three-dimensional model based on the development diagram is shown in Figure 1, which has been implemented in the generated set of concrete for the manufacture of membranes at the construction site using a formless concreting [6, 7, 8,9].

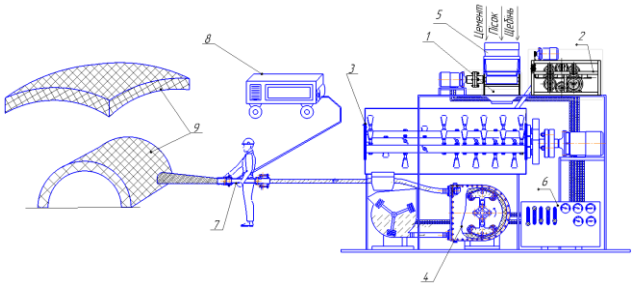


Fig. 1: Schematic diagram of the process small-sized equipment kit for the manufacture of complex geometric shape concrete products directly into the construction site by a wet shotcreting using formless concrete: 1 - belt

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feeder, 2 automatic fiber cutter, 3 – three shafted concrete mixer, 4 - universal hose concrete pump, 5 - dosing knot, 6 - hydro distribution knife, 7 - shotgun nozzle, 8 - compressor installation, 9 - objects, which are shaken

During transport as a moving and construction mixtures inactive via line in view of their properties, the concrete pump hose performance can be found according Shvedov-Bingham model

$$\Pi_{техн} = \frac{dT\, d_{тр}^3}{4\mu} \cdot \left(\frac{\Delta p\, d_{тр}}{2L_{тр}} - \frac{4}{3}\tau_0 \right), \quad (1)$$

where $d_{тр}$ - the radius of the pipeline, along which rum concrete mix transported to the consumer via a peristaltic pump concrete no-piston; μ - dynamic viscosity concrete mix; Δp - pressure difference across the ends of the conveying line; $L_{тр}$ - the length of conduit; τ_0 - limiting voltage shear layers of concrete in the pipe relative to each other.

Differential pressure $\Delta p = P_н - P_{вых}$ wherein $P_н$ - the pressure at which the concrete mix is fed to a transport pipeline leaving the concrete pump; $P_{вых}$ - the pressure at which the concrete mix is leaving the transport route.

The $P_н$ is pressure, at which the concrete mix out of the concrete pump hose working section, creates pressure rollers rotating rotor within an angle φ with regard to the existing friction forces (Figure 2.),

$$P_н = \frac{4mw^2 R_\rho \varphi f}{\lambda\pi(m_\rho - 2\tau_{тр})}, \quad (2)$$

wherein φ - the discharge process of the concrete mix working zone; f - friction coefficient, generated between the roller end surface and the outer surface of the flexible hose in the pump housing during rotation of its rotor; λ - drag coefficient of concrete mix movement through the pipeline.

The pressure at the exit from the transport line length $L_{тр}$ is determined according to the relationship:

$$P_{вых} = \frac{4\Pi_{техн} \cdot \rho_0 \cdot v_{ср}^2 \cdot \mu}{\pi\lambda \cdot d_{тр}^2 \cdot L_{тр} \cdot \tau_0}, \quad (3)$$

The coefficient λ is determined based on the conditions that the laminar flow of the concrete mix is observed in the pipeline. The coefficient λ for flexible piping is defined as [2]:

$$\lambda = \frac{68}{\mathrm{Re}} \quad (4)$$

where Re - Reynolds number.

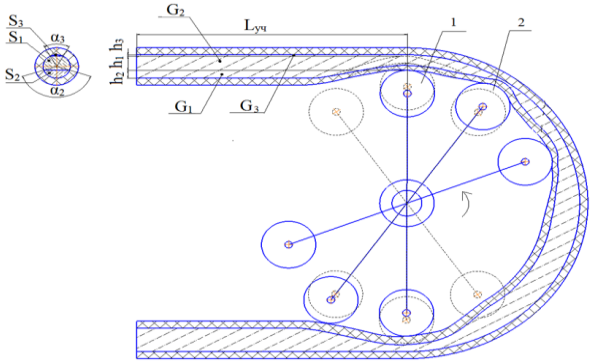


Fig. 2: The estimated circuit for determining the coefficient that takes into account the gradual increase in force that is generated rollers rotor: 1- main pressure roller; 2.3 - additional pinch rollers

Conveying line length is defined as:

$$\lambda = \frac{d_{тр}\Delta p}{\lambda(\rho_0 \frac{v_{ср}^2}{2})} \quad (5)$$

where ρ_0 - the average density of the concrete mixture which is transported through conduit; $v_{ср}$ - average speed of the concrete mix via the transfer line.

Thus, during transportation of concrete through the pipeline, performance of a given set of process equipment in which the machine base is no-piston concrete pump hose depends on the pressure drop occurring in the pipeline $L_{тр}$ length, its deformation properties and design dimensions, physical-mechanical properties of the concrete mix feed.

In this case, it is impossible to neglect those resistances which arise in the path of the concrete mix on the transport line.

Since determined performance is based on the breadboard analysis workflow feeding the mixture through the pipeline.

On the other hand, if the set of performance determined by the base machine performance - a peristaltic pump, its performance can be found from the dependence of [5]:

$$\Pi_{2техн} = 60 \cdot F \cdot v_{ср} \cdot z \cdot K_1 \cdot K_2 \cdot K_3, \quad (6)$$

where F - the cross-sectional area of the hose in the concrete pump, m^3; Z - number of central rollers in the pump; K_1 - coefficient taking into account the gradual increase in the force generated by the rotor during compression roller hoses outside of its working parts within the machine housing; K_2 - coefficient that takes into account the gradual increase in the force generated by the rotor during compression rollers outside the hose into its working portion inside the machine body; K_3 - coefficient taking into account the reliability of the pump hose with the voltages that appear; $v_{ср}$ - factor which takes into consideration the conditions of feeding concrete pump mixture from the transfer line in view of its characteristics.

When using a peristaltic pump concrete no-piston as basic machine sets its operation power requirement is determined based on the relationship:

$$P_{ов} = k_{зм} \cdot \Pi_{техн}(Q)_{бнс} \cdot \rho_{0бс} \cdot v_{ср}^2 \,/\, 1000\eta_{общ} \quad (7)$$

where $k_{зм}$ - coefficient taking into account the power headroom to overcome the resistance to movement of the mixture through the line; $\eta_{общ}$ - total efficiency concrete pump; $\eta_{общ} = \eta_{мех} \cdot \eta_{гидравл}$.

To calculate the reliability of different types of concrete pumps are the the construction block diagram proposed.

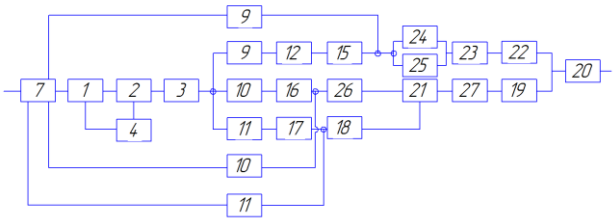


Fig. 3: Block diagram of no-piston universal concrete pump with hydraulic drive: 1 - tank; 2 - pump; 3 - filter; 4 - safety valve; 9, 10, 11 - the control valve; 7 - check valve; 12 - a flow regulator; 15, 16 - high-torque motor; 17 - cylinder; 18 - the conical tip; 19 – no-piston concrete pump with a hydraulic drive; 20 flexible hose; 21 - concrete pump rotor; 22 - tank with a concrete mixture; 23 - haymaker; 24, 25, 26, 27 - pinch rollers

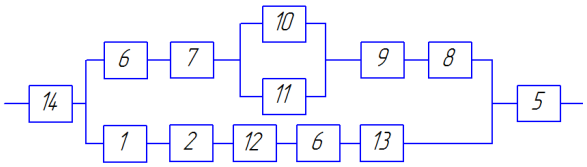


Fig. 4: Universal no-piston concrete driven pump block diagram:
1, 6 – gear motor; 2, 7 - clutch, 5 - a flexible hose; 8 - concrete mix hopper; 9 - with the agitator shaft; 10, 11, 12 - bearings; 13 - rollers; 14 - electric starter

Provides a comparative analysis of no-piston concrete pump pipe reliability with two kinds of drives showed that the greater reliability and uptime operation has a concrete pump with a hydraulic drive.

The universal hose concrete pump [3] is used as such a set of basic machine which, by virtue of their structural features and the hydraulic actuator can be operated with different performance P_{tehn}= (5 ... 15^{m3}/ h) on the hoses of various diameters (d = 32 , 50, 75 mm).

Thus, it should be borne in mind that the performance of the concrete pump hose as a set of basic machine may affect the dynamic characteristics: in particular moments of starting and braking concrete high-torque motor [9]. In this regard, it is necessary to analyze the reliability of its work.

For this purpose, a new reliability concrete pump coefficient determined that is mapped to the reliability of existing concrete pump coefficient.

For the new concrete pump:

$$k_{н2} = \frac{G_1 + G_2 + G_3}{G_1 + G_3} = 1,43,$$

wherein G_1, G_2, G_3 - respectively, by weight of the concrete mix in the hose, which prevents its deformation at the initial moment of rotation by the action of the central roller, the weight of the concrete mix which is pressurized additional roller weight concrete mix, which is in the deformed portion of the hose under the influence of the central roller.

For conventional concrete pump design with one central roller:

$$k_{н2} = \frac{G}{G - G_3} = 1,02,$$

where G - total weight of the concrete mixture which moves through the hose under pressure rollers.

Calculation of safety factors of the new concrete pump showed it advantageous side of the structure.

Calculation of cycles both machines can be produced according to the relationship:

$$z_ц = \frac{3600 \cdot T \cdot k_н}{T_1 + T_2}, \quad (8)$$

where T - uptime concrete pump [9], T_1 - concrete pump rotor acceleration time, T_2 - braking time.

Figure 5 is a graphical depiction of the angular speed of the rotor acceleration Concrete aversion and Figure 6 - the dependence of the angular speed of the rotor from the deceleration time .

Calculation of operating cycles of the new concrete pump with hydraulic drive and operate the machine showed that the service life of the new car is 25% more than the resource hours in modern concrete pump hose.

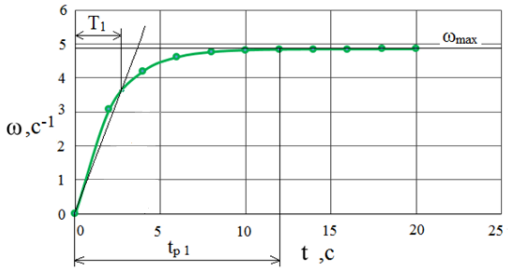


Fig. 4: Dependence of the angular speed of the rotor of the new concrete pump from starting time

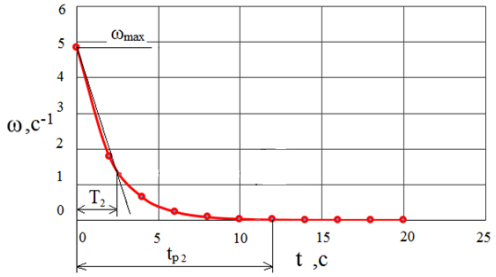


Fig. 5: The dependence of the angular speed of the rotor of the new concrete pump on time of acceleration

Efficiency of the considered technological equipment set also depends on the stable concrete pump supply conditions mixture into the conduit. Analysis subjected new job with a mechanical pump and hydromechanical actuators [10].

The estimation was made from the coefficient supplying unevenness:

- the hydraulic actuator:

$$\delta_{бн\,г} = \frac{4(d_{шл}\pi n R^* - k_{эпр} h_щ \sqrt{\frac{2\Delta p_{бн}}{\rho_0}})}{d_{шл}(w_1 + w_2)} \quad (9)$$

where the $d_{шл}$ -diameter of the hose, through which the mixture is fed;

R^* - radius of the roller mounted with respect to the center of the solution;

$k_{эпр}$ - the equivalent flow coefficient allowing flow of the mixture at sequential arrangement of the roller;

$h_щ$ - gap which is formed between the wall of the hose compressed under the action of the central roller;

$\Delta p_{бн}$ - pressure difference across the pump;

ρ_0 - the average density of the concrete mix;

w_1, w_2 - respectively the minimum and maximum angular speed of the rotor.

When the actuator is mechanical:

$$\delta_{бн\,м} = \frac{4(d_{шл}\pi n R^* - k_{эпр} h_щ \sqrt{\frac{2\Delta p_{бн}}{\rho_0}})}{d_{шл} v_л} \quad (10)$$

wherein $v_л$ - the movement velocity of the mixture through the hose in the concrete pump housing.

Determining ratios $\delta_{бн\,г}$ and $\delta_{бн\,м}$ found that the concrete pump with a hydraulic drive, compared with the mechanical, pulsation supplying the mixture through conduit 15% less.

Therefore, considered a set of equipment with a basic concrete pump hose in the presence of the hydraulic drive, as showed studies, due to the reduced amount of ripple, can guarantee reliable operation in the construction site.

The results of the research you can use it to perform the wet shotcrete full mechanization method of the process with workflow automation.
Such a process kit can be used for computer modeling workflow construction of buildings and structures.
The versatility of such a kit is explained by using the following features to:
- coating of shotcrete and shotconcrete at using method formless concreting;
- manufacture of concrete constructions and products with a complex geometric shape directly into the construction site using a wet shotcreting process in a formless concreting;
- transportation of building mixtures and solutions to the place of consumption;
- preparation of mixes and different mobility solutions and destination.
Technology package includes equipment, which is patented in Ukraine. The presence of these equipment types allows the complete use it to perform the entire operating cycle, starting from the concrete mix preparation (fiber-reinforced concrete mixture) and completing the separate works using gunning nozzle with annular end. In this case, if necessary fiber-reinforced concrete mixture, the process begins with the cutting of fiber elements with their simultaneous supply to three-shaft mixer, which also serves other prepared mixture components. From the mixer the mixture already ready at the same time fed in the concrete and further along the conduit to a working nozzle.
Developed new three-dimensional dynamic equipment model in the technological kit form for the buildings construction, as well as the concrete products manufacture and complex geometry structures using a formless concreting actually on playground. The set included an arrow manipulator placed thereon with the nozzle (Figure 6 and Figure 7.).

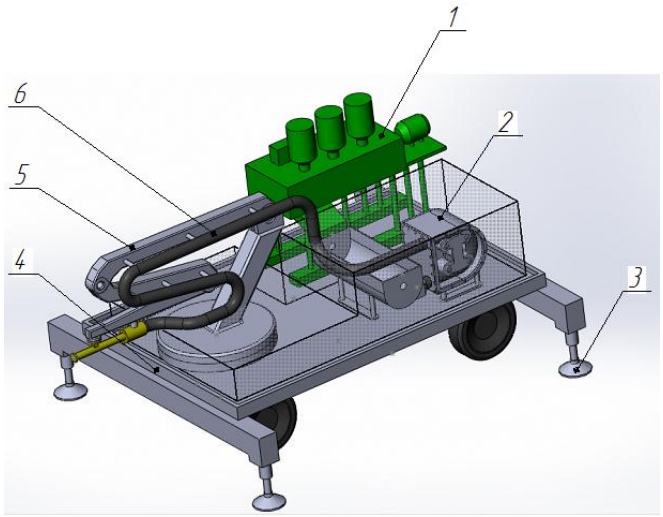
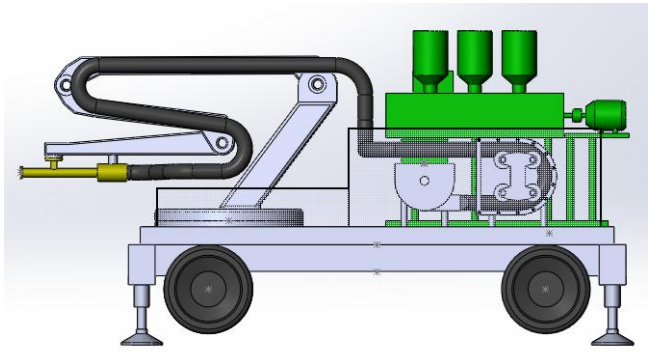
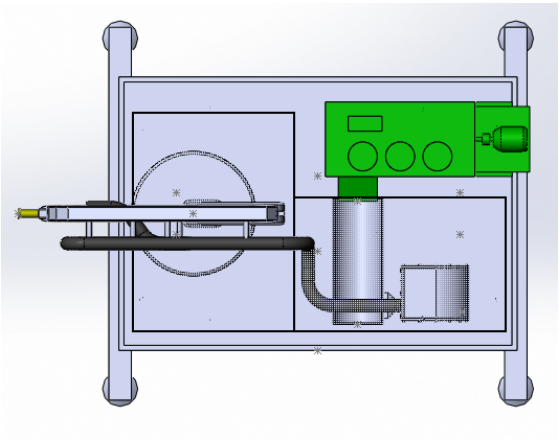


Fig. 6: Three-dimensional dynamic model with a new set of small-sized equipment (isometric): 1 - three-shaft mixer, 2 - universal no-piston concrete pump, 3 – outriggers, 4 – platform, 5 – working arrow, 6 - hose through which the concrete mix is transported



a)



b)

Fig. 7: The three-dimensional dynamic model with a new set of small equipment: a) - a side view, b) - the top view.
Thanks to the three-dimensional modeling tools has become possible to take into account the degree of freedom of each link mechanism to check the stability of the equipment at different positions of the manipulator and visualize the operation of the process kit during the shotcrete work.

Thanks to automation equipment (when using self-regulating technical equipment, economic and mathematical methods and control systems, the release of the person from participation in the processes of energy transfer and use in work processes of construction, substantial reduction of direct human intervention in the implementation of certain operations) and the possibility of three-dimensional modeling is very convenient and required is the ability to check the reality of the proposed action designed the system in a variety of conditions.
Figure 8 shows the free trajectory of the working motion of the nozzle when applying mortar on the surface to be treated by a wet shotcrete.

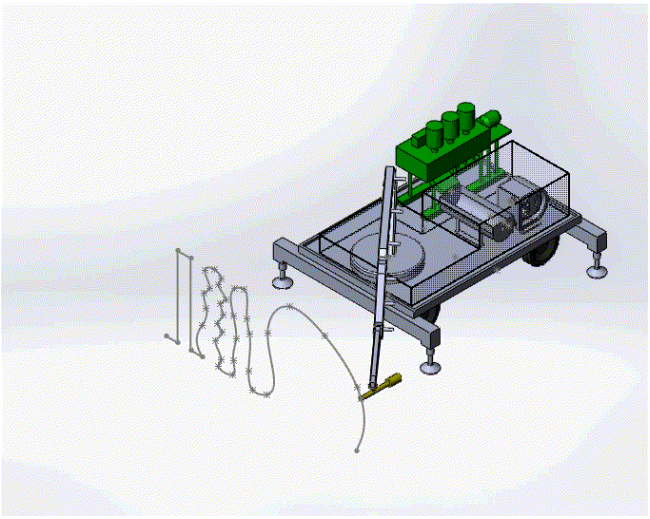


Fig. 8: Free movement trajectory of the nozzle

Computer control means a pneumatic automation shooting process. It is possible to provide automatic operation for moving all the system parts to ensure the most efficient boom-arm movement site, the working conditions and properties of mortar, which is applied to the surface (Figure 9).
At the same time, it is possible to specify the conditions under which the nozzle is always the normal with respect to the work surface.

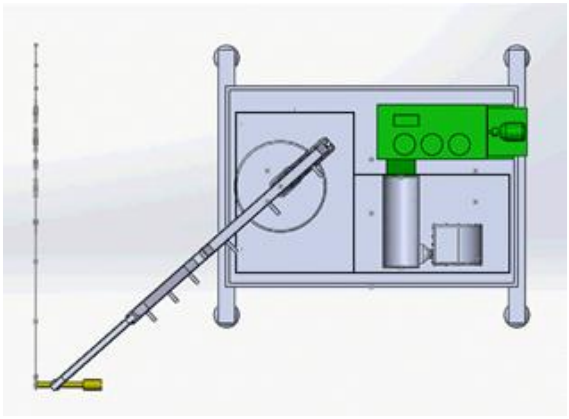


Fig. 9: The position of the nozzle along the normal to the machined surface

Operation of breadboard automation is only possible by means of a specific algorithm, which takes into account the workflow construction site conditions, especially the surface on which working mixture is sprayed, and provides the most efficient path of movement of the nozzle in accordance with adjustments arising during operation, taking into account the features that could not be foreseen in advance (windy weather emergency an increase in pressure, etc.).

This algorithm was developed and is presented in Figure 10.

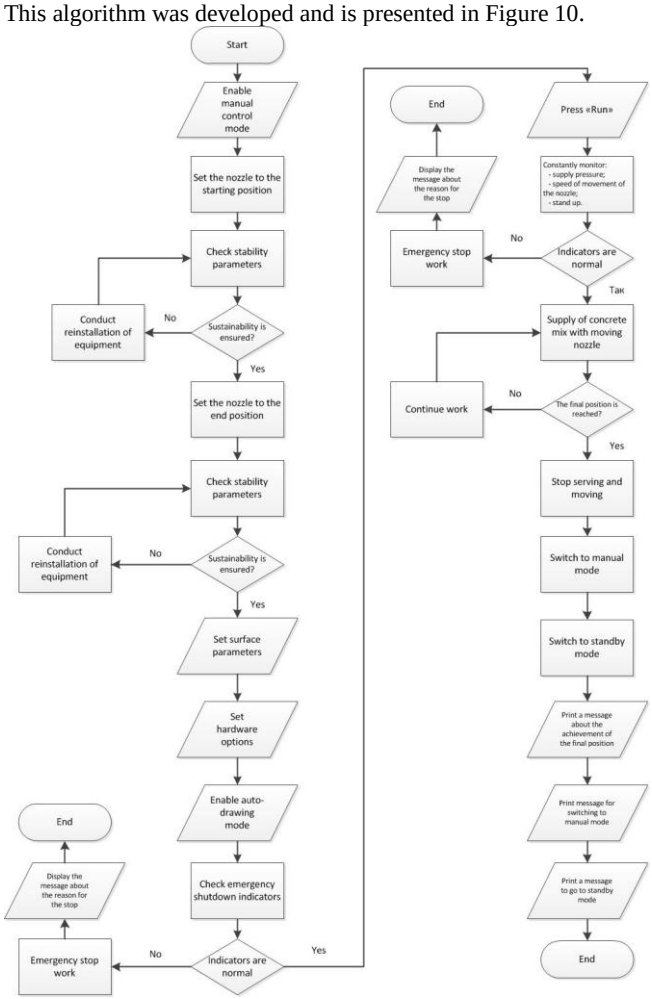


Fig. 10: The algorithm of automatic control the working nozzle using breadboard with new small-sized equipment

Thus, developed a computer model of the new 3D equipment in view of automatic control algorithm that allows the nozzle operation to create a full and effective process when both formless concreting when laying reinforced concrete and in the manufacture of designs and products directly to the construction site.

3. Conclusions

1. Showing advantageous aspects of the working mixture application process with three-dimensional model of new process kit small equipment for its implementation.
2. The research compared the proposed set using effectiveness as a new peristaltic pump and modern machines: the new pump life is in 25% higher than the resources of the contemporary concrete pump hose work at a reduced flow pulsations mixture by pipeline to 15%.
3. A three-dimensional dynamic process model developed with a new set of small equipment for the building objects erection using the formless concreting method .

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