Formless concreting new small-size equipment universal technological set energy consumption features determination

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Abstract. A scheme for the implementation of shotcrete work in a construction site using a new technological kit is presented. The basic machine of this kit is a hose concrete pump. The design of a pump with a hydraulic drive is considered, which makes it possible to adjust the rotation frequency of the working body of the concrete pump in a wide range and reduce the level of pulsation of the mixture at the outlet of the concrete pump. Energy consumption is considered as a universal set of new small-sized equipment, the structure and circuit diagram of which are presented in the article. The dependencies for determining the power required for machines - modules of this kit are given. The effectiveness of the kit for continuous concreting using the wet gunning method in a building site due to the combination of separate operations over time is shown.

1. Introduction
The use of technological complexes and universal technological kits directly on the construction site conditions is at present an actual problem. Technological kits deserve particular attention in which machine modules are mounted on a common frame allowing to fulfill work with complete computerization and all technological operations automation [1, 2]. At the same time, the use of technological kits, instead of complexes, allows to combine all operations in time, which contributes to 15 to 20% increase in the construction processes objects productivity [3, 4].

All machines and equipment, which are modules of technological kits, are patented in Ukraine and can work in purely specialized kits, and be part of a universal hydraulic kits wide range.

The general technological kit structural scheme with the new small-size equipment is presented at figure 1.

According to the scheme in figure 1, one of the following machines operating in cascade mode can be used as a mixer [5]:
- three-shaft concrete mixer;
- gravity-forced concrete mixer;
- concrete mixer with belt-blade shaft.

One of such kit modules may be the universal hollow concrete pump installation [6, 7].
The basic scheme of the small-sized equipment for formless concreting technological set, which corresponds to the structural scheme in figure 1, is presented in figure 2.

The kit productivity under consideration is determined by its base machine performance. The basic machine in this case is a mixer. As the case of the mixer, the technological kit loading hopper is used. The concrete pump technical productivity \( P_{\text{techn.pump}} \), at the same time, should be the same as the mixer's technical productivity \( P_{\text{techn.mix}} \):

\[
P_{\text{techn.pump}} = P_{\text{techn.mix}}.
\]

[8].

The operating principle of the kit is as follows. From the dispensing unit 1 to the intermediate bunker 2, the discharged components of crushed stone, sand and cement are delivered in proportion to the concrete mixture composition. The mixer housing is also fed from a dosated portion of water. The time of loading of the intermediate bunker must coincide with the portion preparation time of the from the previously loaded components in the mixer. The time of gradual supply of the ready mixture from the receiving tray into the concrete pump and from the concrete pump to the working nozzle coincides with the time of the wet torcreting surface being processed. Thus, there is a technological operations combination while reducing the works execution time by 20 to 25% and energy consumption by 15 to 20%.

**Figure 1.** The universal technological set of small-sized equipment for formless concreting using the wet gripping method in the construction site conditions block diagram.

**Figure 2.** Technological set of small equipment for formless concreting in the construction site conditions.

1', 1'', 1''' – dosing unit; 2 – intermediate bunker; 3 – mixer; 4 – horizontal belt shaft; 5 – reception tray of the finished concrete mix; 6 – universal non-porous hose concrete pump; 7 – general support frame; 8 – hydro-distribution unit; 9 – control cabinet; 10 – nozzle with annular nozzle
In order to determine the technological unit power consumption under consideration (figure 2), its hydraulic circuit (see figure 3) [9, 10] should be analyzed further.

Required liquid in the hydraulic motors M1, M2 are installed with the help of inductors DR1, DR2, DR3.

The required kit (mixer) performance is set with the help of the DR4 throttle, and the required number of components for the mixture preparation by DR5, DR6, DR7 inductors.

Distributors P7, P8 respectively provide supply from the metered components from the intermediate hopper to the mixer; distributor 8 provides the delivery of the finished mixture to the receiving tray, from which it gets into the concrete pump. The gates, which overlap the crushed stone, sand, and cement bunkers openings are controlled by HC2, HC3, HC4, the shaker of the intermediate bunker - under the control of HC5, the finished mixture delivery from the mixer to the receiving tray – HC6.

**Figure 3.** Hydraulic circuit of the small-sized equipment universal technological complex for formless concreting drive.

T – tank; M – electric motor; P – screw pump; SV1 – safety valve; F – filter; PG – pressure gauge; P1, P2 – respectively, concrete mixer operation distributors and concrete pump; P3 – the concrete pump performance regulator; P4, P5, P6 – hydraulic distributors control valves of crushed stone, sand, cement buckets; M1, M2 – respectively the mixer hydraulic motor and the concrete pump.

2. Theoretical part

The required finished concrete mixture flow from the mixer to the working nozzle is provided by the DR8 and DR inductors.

The total cost of the power may be represented as follows:

$$\sum P_{total} = P_1 + P_2 + P_3 + P_4,$$

where $P_1$ – the cost of power needed to operate the dosing unit; $P_2$ – power consumption, which ensures the process of preparing the mixture in the mixer; $P_3$ – power consumption, which is spent on the non-porous hose concrete pump operation, which ensures the shutter-work performance without sealing concrete; $P_4$ – power consumption, which is spent on the machine-cutter of fiber elements while working on the kit on fiber-concrete mixes.

According to the hydraulic diagram (figure 3) in the metered site opening of the cervical filing works with containers of the relative quantity of cement, sand, gravel is carried out by the relevant hydraulic cylinders GIZ4, GCM3, TZ2, the work of which provides a hydraulic pump P from the main engine M.
Output power of the hydraulic cylinder (W) \( P_{HC\text{ max}} = F_{HC\text{ max}} \cdot V_{HC\text{ max}} \), where \( F_{HC\text{ max}} \) is the maximum force on the hydraulic cylinder rod, H; \( V_{HC\text{ max}} \) – maximum speed of the hydraulic cylinder, m/s.

Thus, the cost of power to work the dosing unit defined as, W:

\[
P_i = F_{1HC\text{ max}} \cdot V_{1HC\text{ max}} + F_{2HC\text{ max}} \cdot V_{2HC\text{ max}} + F_{3HC\text{ max}} \cdot V_{3HC\text{ max}},
\]

where \( F_{1HC\text{ max}} \), \( F_{2HC\text{ max}} \), \( F_{3HC\text{ max}} \) are respectively, maximum forces on the hydraulic cylinders that control the silos, sand, and cement bins; \( V_{1HC\text{ max}} \), \( V_{2HC\text{ max}} \), \( V_{3HC\text{ max}} \) – respectively, the maximum speeds of the above mentioned hydraulic cylinders HC2, HC 3, HC 4.

Power consumed for the preparation of concrete mixtures in the mixer, kW:

\[
P_2 = P_{21} + P_{22}
\]

where \( P_{21} \) is power required to operate the tape auger, W; \( P_{22} \) is the power required to operate the blade shaft, W.

\[
R_s = \frac{[\omega_s \cdot M_{t,s} + F_{f,s} \cdot V_{abc} \cdot z_1 + c \cdot \rho_0 \cdot S_{av,d} \cdot \omega_s^3 \cdot k_{vc} \cdot z_{t,s} \cdot (D^2 - D_{in,d,s}^2)] + 32 \cdot \pi^2 \cdot k_s \cdot \pi \cdot c \cdot \rho_0 \cdot S_{av,d} \cdot \omega_s^3 \cdot f_1 \cdot z_{t,s} \cdot \tan \alpha_{av,d} \cdot \sin \alpha_{av,d} (D_{ex,d,s}^2 - D_{in,d,s}^2)]}{80 \cdot k_s} \cdot \frac{1}{1000 \cdot \eta_{sh} \cdot \eta_h},
\]

where \( \omega_s \) – angle of shaft rotation, \( c \); \( M_{t,s} \) – torque of the shaft, H-m; \( F_{f,s} \) – friction force that occurs when the concrete mix particles on the blade surface, H; \( z_1 \) – number of blades on the shaft; \( V_{abc} \) – absolute particles velocity of the mixture on shaft blades, m/s; \( c \) – blade movement resistance coefficient when mixing the concrete mixture in the direction of its movement in a circle; \( S_{av,d} \) – screw increments along its average diameter, m; \( k_{vc} \) – case volume filling coefficient; \( z_{t,s} \) – number of screw turns; \( D \) – diameter of the mixer housing, m; \( D_{ex,d,s}, D_{in,d,s} \) – respectively external and internal screw diameters, m; \( \rho_0 \) – average density of concrete mix, kg / m³; \( f_1 \) – mixture friction coefficient when moving concrete mixture particles on the mixer housing surface; \( \alpha_{av,d} \) – screw lifting line angle average diameter, m; \( k_s \) is mixture return factor; \( \eta_{sh}, \eta_h \) – according to drive efficiency shaft drive, belt screw.

The total power consumption for transporting the concrete mixture through the pipeline using the new universal hose concrete pump is defined as:

\[
P_3 = P_{31} + P_{32},
\]

where \( P_{31} \) – power required to rotate the concrete pump rotor with the required speed, W; \( P_{32} \) – power required for the movement of the concrete mixture on the flexible hose in the concrete pump housing, W.

Thus:
where \( k_{cf} \) – capacity factor; \( G_{c,m} \) – weight of the concrete mixture under the clamping rollers influence, H; \( k_{fr} \) – coefficient of friction, as a result of the parietal effect between the inner wall of a flexible hose and concrete mixture in the process of its movement; \( F_{pr,rol} \) – pressing rollers force to the outer surface of the hose to the pump working space, N; \( k_{fr,h} \) – rolling friction coefficient of rollers on the hose surface, m; \( r_{roll} \) – roll radius, m; \( n \) – rotor rotation frequency, \( \text{min}^{-1} \); \( R_{av,v} \) – average distance between the rotor axis and the roller face, m; \( \eta_{bn} \) – concrete pump efficiency; \( S_h \) – sectional area of the inner diameter of the hose, which is enclosed in concrete pump housing, \( m^2 \); \( \Delta \rho_3 \) – pressure difference at the ends of the transport pipeline, Pa; \( V_{av} \) – average speed of the concrete mix on the flexible hose, m/s; \( k_{ixr} \) – coefficient taking into account the length of the transport pipeline; \( \eta_{cl} \) – coefficient of hydraulic losses in the transport pipeline.

The presence of a universal non-porous hose concrete pump in the considered technological kit provides the appropriate concrete mixture injection pressure through the pipeline to the working nozzle. In this case, the kinetic energy of air-concrete particles stock flow that is sprayed onto the surface treated with a nozzle can be found using the dependence [11]:

\[
K = \sum_{i=1}^{n} \sum_{l=1}^{m} \frac{m_i(r_l) + m_s(r_l)}{2} V_s^2(r_l) + \sum m_{disp,s} \cdot V_{cp}^2,
\]

(7)

where \( m_i \) – the filler mass in the k-th cross flow section; \( m_s \) – total mass of the soluble component in the k-th flow section circle; \( V_s \) – the filler radius particles velocity \( (r_l) \) in the k-cross flow section; \( m_{disp,s} \) – the mass of the dispersed soluble component in the flow k-cross section; \( V_{cp} \) – the velocity of the soluble component particles in the k-cross flow section.

Taking into account the geometry of the air-concrete flow, the kinetic energy stock can be represented as:

\[
K(L) = \frac{1}{2} \int_0^{2\pi} \int_0^{R(L)} m(r,L,\varphi) \cdot V^2(r,L,\varphi) dr \cdot d\varphi,
\]

(8)

where \( R(L) \) – the cross section radius of the flow at a distance \( L \) from the nozzle cut; \( m(r,L,\varphi) \) – the particles mass in the jet section at a distance \( r \) from the jet axis; \( V(r,L,\varphi) \) – the particles velocity in the jet section on the radius \( r \) and at a distance \( L \) from the nozzle cut.

The average weighted particles velocity of the concrete mixture in the flow is determined, according to the dependence:

\[
V_{cp}(L) = \frac{\int_0^{2\pi} \int_0^{R(L)} m(r,\varphi,R_c) \cdot V(r,\varphi,R_c) dr \cdot d\varphi}{\int_0^{2\pi} \int_0^{R(L)} m(r,\varphi,R_c) dr \cdot d\varphi},
\]

(9)
where $R_x(L)$ – radius of the jet section on the length $x$ from the nozzle cut, m; $m(r, \varphi, R_x)$ – particles mass with radius, which are at the point with polar coordinates, kg; $V(r, \varphi, R_x)$ – particles velocity with radius $R_x$, which are at the point with polar coordinates $(r, \varphi)$, m/s.

Knowing the weighted average particle velocity for the entire air-concrete mixture flow, it is possible to predict the compression efficiency and rebound when pneumatic molding. When using the technological kit that is considered for work on fiber concrete mixtures, when the automatic machine-cutter of synthetic fibrous fibers (figure 1) is included into the kit, the power is spent on the feeding fibrous threads process to the cutting head $P_{41}$ and the cutting process extended strands $P_{42}$. In this case, the power consumption on the machine-cutter operation is determined according to the following dependence [12]:

$$P_4 = \frac{F_r \cdot V_r \cdot \eta_1 \cdot \eta_2}{\eta_1 \cdot 4 \cdot \eta_2} + \pi \cdot d_{syn.th}^2 \cdot z_2 \cdot r_{kh}. \cdot \tau_{syn.th} \cdot \omega_{kh} \cdot k_{cyc} \cdot \sin \alpha,$$  \hspace{1cm} (10)

where $F_r$ – effort that creates the mechanism for supplying synthetic yarn, H; $\eta_1$ – efficiency value, taking into account the power consumption to overcome the friction forces that arise between the rollers and threads in the tow; $z_1$ – number of niches in a tourniquet, which are stretched by rollers; $z_2$ – number of contact points of threads with rollers surfaces; $d_{syn.th}$ – diameter of synthetic thread, m; $V_r$ – supply reels rotation linear speed, m/s; $r_{kh}$ – radius of the circle knife head, m; $\tau_{syn.th}$ – the synthetic thread strength on the cut, MPa; $\omega_{kh}$ – angular rotation speed of the knife head, c\(^{-1}\); $k_{cyc}$ – cyclicity value; $\eta_2$ – knife head efficiency of the drive of the automatic machine-cutter; $\alpha$ – the angle under which the synthetic yarns strand is made.

The given dependencies for determining the universal technological set of small-sized equipment power consumption allow to reasonably approach to the choice of its hydraulic drive [13].

Such a set of equipment, except for the direct works assignment by the formless concreting method, may be, if necessary, used to perform certain operations: preparation of mixes for various purposes, their transportation in the construction site, the concrete works in compressed conditions, in particular, directly inside the buildings. The possibility of its use for full 3D printing while erecting construction objects deserves particular attention.

The advantage of such a kit also is the ability to carry out construction work in the shortest possible time due to the simultaneous its certain machine-modules operation.

Thus, the use of the proposed universal technological equipment kit in the mode of continuous operation allows it to be operated with increased productivity at reduced energy costs due to the individual operations implementation in combination with time.

3. Conclusions

1 The structural and fundamental schemes of the new universal technological kit of small-sized equipment for off-formwork concreting in the conditions of the construction site are shown.

2 The dependencies for determining the power consumption on the work of the constituent machine modules that are part of the technological kit being considered and which allow you to determine the total power of the kit are given.

3 These are the use of the offered kit, which confirm its versatility.
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