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Univerzalna građevinska oprema malih gabarita za rad na gradilištu

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Brojni infrastrukturni i stambeni objekti su predmet razaranja i oštećenja, pa su i neophodni radovi na njihovim popravkama i rekonstrukcijama. U takvim uslovima, najveći problem predstavlja upotreba građevinske opreme manjih gabarita koja olakšava izvođenje čitavih ciklusa radova direktno na gradilištu. Veoma je važno razvijati nove tehnološke komplete takve opreme koja se koristi na gradilištima. Razvoj takve opreme obuhvata sistematski pristup izučavanju predloženih kompleta kao i rezultata istraživanja prenosa od ishoda ispitivanja same opreme pa do industrijskih uzoraka. Takav pristup pokazuje efikasnost u razvoju tehnoloških kompleta koji se zasnivaju na manipulatorima i kombinovanju operacija.

Ključne reči: mali gabarit, oprema, beton, smeša

1. UVOD

Građevinsku opremu manjih gabarita čini univerzalna oprema (u zavisnosti od uslova i tehnoloških specifičnosti izvođenja radova) koja se montira na zajedničku osnovu ili okvir. Takvu opremu je razvio Departman za građevinsku mehanizaciju na Državnom univerzitetu građevinarstva i arhitekture u Harkovu (Ukrajina).

Predložena oprema se koristi u sledećim oblastima:

- Građevinske i industrijske konstrukcije,
- Hidrotehničke konstrukcije,
- Rekonstrukcija zgrada i objekata,
- Betoniranje netradicionalnih zgrada i objekata,
- Priprema betonske smeše različite mobilnosti i oznake,
- Priprema smeše koja se brzo stvrdnjava, itd.

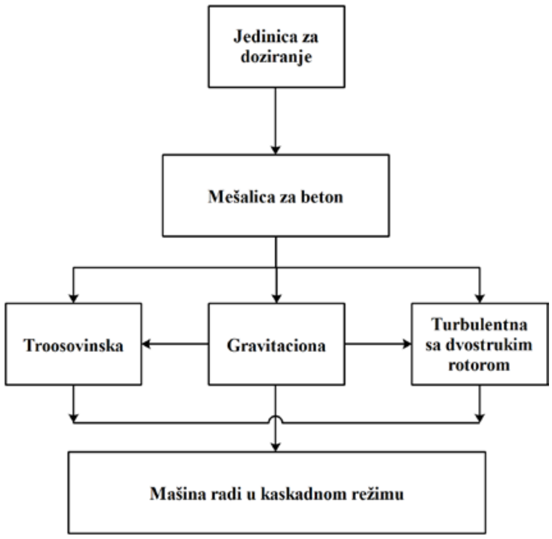
Tehnološka oprema koja se preporučuje za upotrebu na gradilištima je namenjena za:

- pripremu i transport betonske smeše koja se može koristiti u različite svrhe, uključujući suve i vlaknaste betonske smeše sa svim tehnološkim operacijama;
- radove na rekonstrukcijama (restauratorski radovi) pomoću metode vlažnog mašinskog malterisanja na većini objekata u Harkovu i drugim gradovima u Ukrajini;
- ostale radove počev od pripreme građevinskih smeša pa do gipsanih radova.

Tehnološka oprema se sastoji od delova koji su zasebno ispitani u građevinskoj industriji. Neki primeri date opreme su prikazani u radu.

2. PRIPREMA BETONSKE SMEŠE KOJA SE KORISTI U RAZLIČITE SVRHE

Princip rada ovakvih mešalica je kreiranje kompleksnih čestica smeše u radnom prostoru mašine, koji olakšava intenzivan i brz proces mešanja sa koeficijentom ispune (Кзо = 0,7…0,8). Pri tome, mogu se uspešno kombinovati sledeći radni principi: gravitaciono i prinudno mešanje.



Sl. 1. Radni principi mešanja

3. PRIPREMA SMEŠE KOJA SE KORISTI U RAZLIČITE SVRHE I NJEN TRANSPORT CEVIMA DO POTROŠAČA ILI RADNE BRIZGALJKE

Sve radne mašine i metode koje obuhvataju navedenu opremu su patentirane u Ukrajini.

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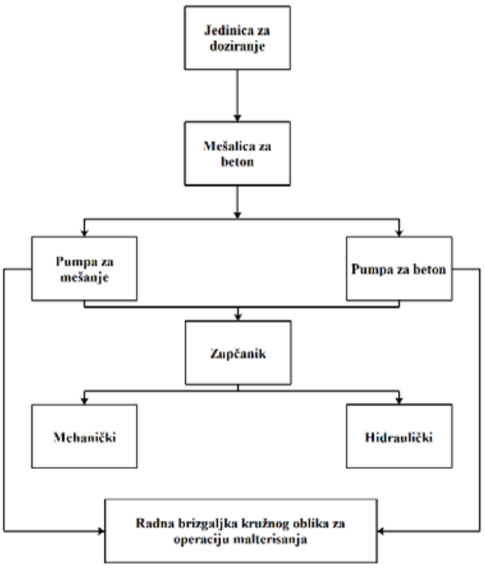
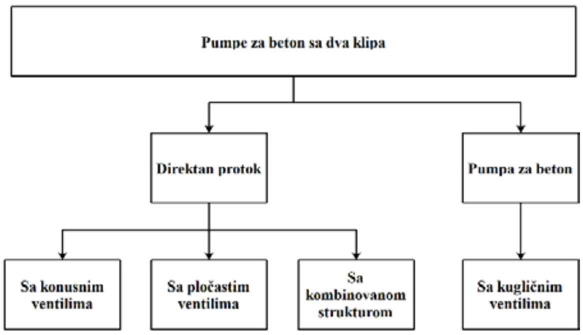
Tehnološki kompleti sa navedenom opremom su namenjeni radovima čiji kapacitet iznosi $П_{техн} = 3…5$ m^3/h, i za manji obim radova primenom procesa vlažnog mašinskog malterisanja i sa potpunom mehanizacijom celog ciklusa.



Sl. 2. Princip pripreme betonske smeše

Pumpe za beton koje se najčešće primenjuju u ove svrhe date su na sl.3.

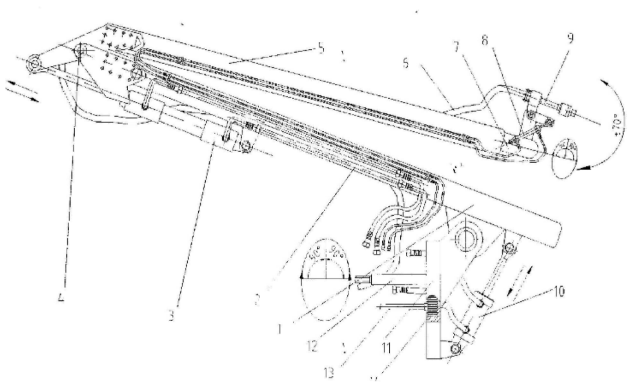


Sl. 3. Pumpe za beton

Od svih razvijenih i ispitanih pumpi za beton, pumpa za beton sa direktnim protokom koja ima konusne ventile (sl. 4a) i pumpa za beton sa direktnim protokom koja ima pločaste ventile (sl. 4b) pokazale su se kao najpouzdanije i najviše upotrebljavane [3].

S obzirom na probleme koji nastaju prilikom malterisanja u ručnom radnom režimu, javlja se potreba za razvijanjem manipulatora sa odgovarajućim softverom [4]. Na slici 5 prikazana je predložena konstrukcija manjeg manipulatora koji se može postaviti na šasiju motornog vozila i koji se može koristiti za mašinsko malterisanje. Manipulatori omogućavaju da građevinska smeša dođe do radne brizgaljke/mlaznice prilikom procesa malterisanja. Princip rada manipulatora prikazan je u sledećim redovima. Strela manipulatora se okreće oko osovine [12] do ± 90°.

Sl. 4. Pumpe za beton sa direktnim protokom i dva klipa:
a) sa konusnim ventilima,
b) sa pločastim ventilima.



Sl. 5. Manipulator za dovođenje građevinske smeše tokom malterisanja

1 – Donji deo strele; 2 – Gumeno crevo; 3 – Hidraulični cilindar za podizanje gornjeg dela strele; 4 – Kuglični zglob; 5 – Gornji deo strele; 6 – Crevo; 7 – Vrh strele; 8 – Hidraulični cilindar za okretanje brizgaljke; 9 – Radna brizgaljka;10 – Hidraulični cilindar za podizanje donjeg dela strele; 11 – Obim zupčanika; 12 – Osovina; 13 – Priključno vratilo;
14 – Mali zupčanik za okretanje strele

Da bi se povećala visina dizanja brizgaljke, donji deo strele [1] se pomera gore-dole pomoću hidrauličnog cilindra [10] u vertikalnom položaju u opsegu od 95°, dok se gornji deo strele [5] okreće duž kugličnog zgloba [4] pomoću hidrauličnog cilindra [3] u opsegu od 150°.

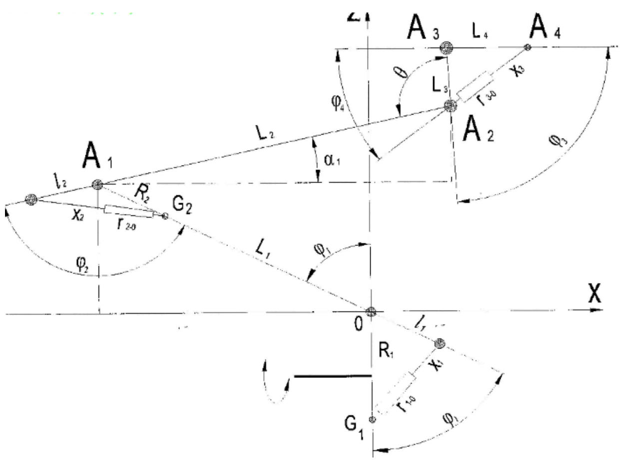
Brizgaljka [9] se pomera gore-dole pomoću hidrauličnog cilindra [8] u vertikalnom položaju u opsegu od 70° i okreće se pomoću zupčanika na vrhu strele u opsegu od ± 90° da bi se zadržao prav ugao mlaza betonske smeše u odnosu na malterisanu površinu.

Prilikom rada, manipulator treba da obezbedi da se brizgaljka kreće po malterisanoj površini. Takođe, potrebno je ispuniti još dva uslova:

- Stalno rastojanje od brizgaljke do malterisane površine,
- Brizgaljka mora biti upravna na malterisanu površinu.

Kad je reč o obliku malterisane površine, ona se može približno predstaviti kao zbir ravnih površina.

Propisano rastojanje od površinskog elementa do malterisane ravni treba ostati nepromenjeno ako se brizgaljka (tačka A4 na sl. 6) pomera u paralelnoj ravni na propisanom rastojanju. Drugi uslov treba biti ispunjen ako se prava linija kreće kroz tačke A_3, A_4 (brizgaljka na sl. 6), ortogonalno u odnosu na propisanu ravan.



Sl.6. Određivanje koordinata brizgaljke na manipulatoru

Koordinate brizgaljke i smera osovine brizgaljke se menjaju u XOZ ravni usled kretanja klipa u hidrauličnim cilindrima 1, 2, 3 (sl. 6).

Minimalno rastojanje od klipova hidrauličnih cilindra do odgovarajuće osovine obrtanja (sl. 6) je prikazano kao $r_{1\text{-}0}$, $r_{2\text{-}0}$, $r_{3\text{-}0}$; hod klipa je označen sa X_1, X_2, X_3; dužina manipulatora je označena sa L_1, L_2, L_3, L_4. Promene ugla obrtanja ϕ_1, ϕ_2, ϕ_3, ϕ_f u delovima manipulatora se određuju prema sledećim formulama:

- Donji deo strele u odnosu na osovinu obrtanja OZ

$$\varphi_1 = arccos\left\{\frac{R_1^2 + l_1^2 - (r_{1-0} + X_1)^2}{2R_1\, l_1}\right\} \qquad (1)$$

- Gornji deo strele u odnosu na donji deo strele:

$$\varphi_2 = arccos\left\{\frac{R_2^2 + l_2^2 - (r_{2-0} + X_2)^2}{2R_2\, l_2}\right\} \qquad (2)$$

- Brizgaljka u odnosu na gornji deo strele:

$$\varphi_3 = arccos\left\{\frac{L_3^2 + L_4^2 - (r_{3-0} + X_3)^2}{2L_3\, L_4}\right\} \qquad (3)$$

$$\varphi_3 = arcsin\left\{\frac{L_3}{r_{3-0} + X_3}\sin\varphi_3\right\} \qquad (4)$$

Koordinatne tačke u ravni ZOX se određuju u zavisnosti od:

- tačke A_1:

$$\begin{cases} X_{A_1} = -L_1\, sin\varphi \\ Z_{A_1} = L_1\, cos\varphi \end{cases} \qquad (5)$$

- tačke A_2:

$$\begin{cases} X_{A_2} = L_2\, sin\,(\varphi_2 - \varphi_1) - L_1\, sin\varphi_1 \\ Z_{A_2} = L_1\, cos\varphi_1 - L_2\, cos\,(\varphi_1 - \varphi_2) \end{cases} \qquad (6)$$

- tačke A_3:

$$\begin{cases} X_{A_3} = X_{A_2} - L_3\, sin\left(\frac{\pi}{2} + \varphi_1 - \theta\right) \\ Z_{A_3} = Z_{A_2} + L_3\, cos\left(\frac{\pi}{2} + \varphi_1 - \theta\right) \end{cases} \qquad (7)$$

- tačke A_4:

$$\begin{cases} X_{A_4} = X_{A_2} + (r_{3-0} + X_3)cos\varphi_4 \\ Z_{A_4} = Z_{A_2} + (r_{3-0} + X_3)sin\varphi_4 \end{cases} \qquad (8)$$

Kada sa manipulator okreće u odnosu na osovinu [12], koordinate Z i Y se menjaju. Prilikom okretanja strele menja se položaj tačke obrtanja donjeg dela manipulatora. U takvim slučajevima referentna tačka se nalazi na drugom mestu kao što je centar obima zupčanika. U novom koordinatnom sistemu:

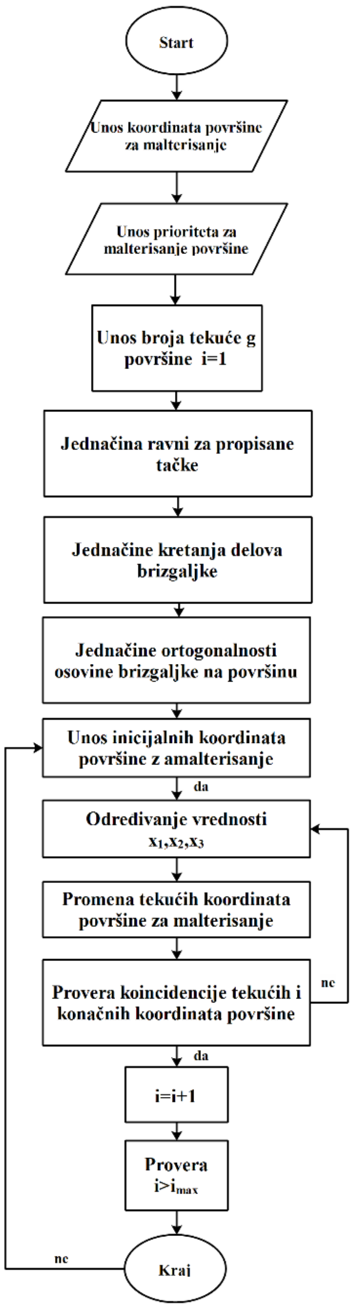
$$X_0 = X_i + X_ц;\; Y_0 = (Z_i + Z_ц)\cos\varphi \qquad (9)$$

gde je φ ugao obrtanja strele.U tom slučaju treba primeniti sledeću jednačinu za opis malterisane površine:

$$AX_0 + BУ_0 + CZ_0 + D = 0 \qquad (10)$$

Napred navedeno istraživanje je dovelo do algoritma koji može odrediti vrednost hoda klipa u svakom hidrauličnom cilindru koji se koristi za rad svih delova strele čime se postiže da se brizgaljka kreće paralelno sa malterisanom površinom (sl. 7).

Na slici 7 prikazan je algoritam koji pruža mogućnost za razvoj softvera za obavljanje procesa mašinskog malterisanja pomoću računara.

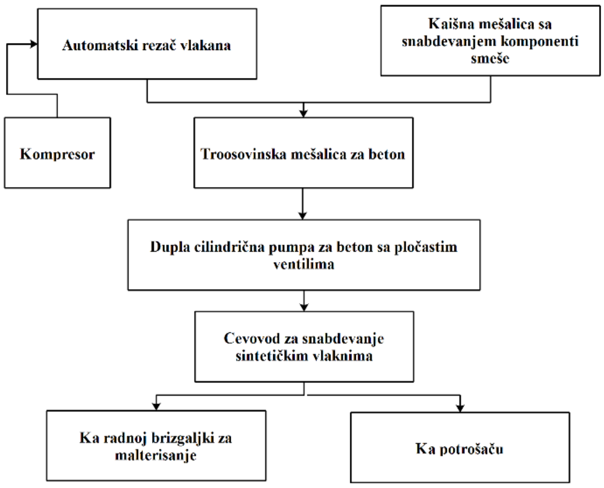


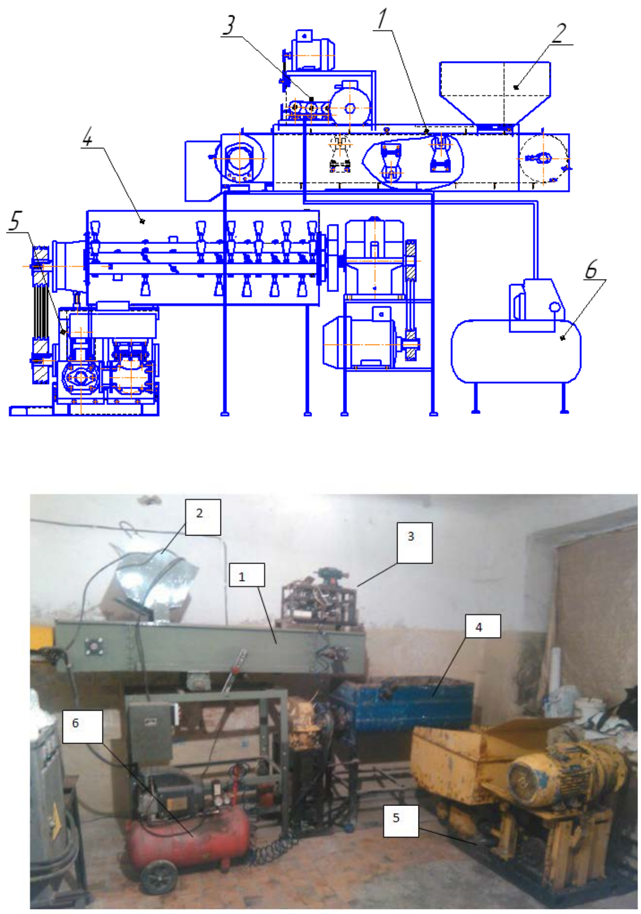
Sl.7. Algoritam koji pruža mogućnost za razvoj softvera za obavljanje procesa mašinskog malterisanja

4. PRIPREMA I TRANSPORT BETONSKE SMEŠE SA SINTETIČKIM VLAKNIMA

Tehnološki komplet opreme prikazan je na sl. 8 [5]. Ovaj komplet opreme ima sledeći princip rada. Suve komponente smeše betona i vlakana se dopremaju od skladišta za napojni vod kaiša [2] do kaiša a zatim do troosovinske betonske mešalice [4]. Istovremeno se dovode i vlakna isečena automatskim rezačem. U desnom delu mešalice suve komponenete se mešaju sa vlaknima, dok se u desnom delu mešalice suva smeša betona i vlakana meša sa vodom.

Po potrebi, krajnja smeša vlakana i betona se doprema iz desne zone do betonske pumpe sa pločastim ventilima [5] a potom se doprema ili do potrošača ili do radne brizgaljke da bi se obavilo malterisanje.





Sl.8. Tehnološki komplet opreme
a) glavna šema tehnološkog kompleta opreme
b) opšta slika tehnološkog kompleta opreme
1 – Napojni vod kaiša; 2 – Skladište za napojni vod kaiša; 3 – Rezač sintetičkog vlakna; 4 – Troosovinska betonska mešalica; 5 – Betonska pumpa sa pločastim ventilima; 6 – Kompresor.

Dakle, ceo proces se može dešavati na gradilištu i pri tome kombinovati sve operacije, od sečenja sintetičkih vlakana do završnog dopremanja smeše betona i vlakana.

Prenos od ishoda ispitivanja do industrijskih uzoraka se primenjuje na čitav tehnološki komplet opreme, počev od betonske mešalice. U slučaju hidrodinamičke sličnosti između ishoda ispitivanja i industrijskih uzoraka mešalica za beton, sledeće uslove treba uzeti u razmatranje: smeše treba pripremati u mašinama koje imaju iste parametre gustine, dinamičke i kinematičke viskoznosti. U tom slučaju treba primeniti jednačinu Rejnoldsovog broja:

$$\mathrm{Re}_{н} = \mathrm{Re}_{м} = idem \quad (11)$$

$$\left\{ \mathrm{Re}_{н} = \frac{\rho_0 \cdot v_{н} \cdot D_{н}}{2}; \mathrm{Re}_{м} = \frac{\rho_0 \cdot v_{м} \cdot D_{м}}{2}, \right. \quad (12)$$

gde su:

- *Reн, Reм* vrednosti ishoda ispitivanja i industrijskih uzoraka opreme,
- $v_н$, $v_м$ brzine obrtanja radnih elemenata ishoda ispitivanja i industrijskih uzoraka mešalica,
- *Dн, Dм* prečnici radnih elemenata ishoda ispitivanja i industrijskih uzoraka mešalica.

Ako primenimo $v_н$, $v_м$, imajući u vidu njihove ugaone vrzine, radi hidrodinamičke sličnosti mašine neophodno je obezbediti da

$$\omega_{н} = \omega_{м} \cdot K_{Д}^{-2},$$

gde su $\omega_н$, $\omega_м$ brzine ugaonog okretanja mešalica a $K_Д$ je koeficijent prenosa.

Stoga determinante minimalnih dimenzija mešalica za beton su prečnik radnog elementa ispod vrha sečiva (D) i njegove dužine (L).

Za današnje vrste betonskih mešalica, primenjuje se uslov

$$\frac{L_{м}}{L_{м}} = \frac{L_{н}}{L_{н}} = idem = m$$

gde je *m* numerička vrednost koja menja parametre opreme u procesu prenosa.

Prenos od ishoda ispitivanja do industrijskih uzoraka pomoću geometrijske skale promene produktivnosti $П_н$ u poređenju sa $П_м$, treba razmatrati na sledeći način:

$$\frac{П_{н}}{П_{м}} = \frac{V_{н}}{V_{м}} \cdot \frac{\omega_{н}}{\omega_{м}} = K_{Д}^{2} \cdot K_{L} \cdot \frac{1}{K_{Д}^{2}} = K_{L} \quad (13)$$

gde su V_H, V_M radne zapremine smeše betona i vlakana; stoga

$$K_{L} = \frac{L_{н}}{L_{м}}$$

predstavlja prenos od ishoda ispitivanja do industrijskih uzoraka mešalice za beton uključujući tehnološki komplet opreme.

Prenos druge opreme koja je obuhvaćena tehnološkim kompletom opreme koja radi sa smešama betona i vlakana ima slični oblik.

Keficijent prenosa do industrijskog uzorka betonse pumpe se određuje na osnovu sledeće formule:

$$K_{R} = \frac{П_{р\,бн}}{П_{р\,бм}} = \frac{\pi \cdot R_{н}^{2} \cdot \vartheta_{ср}}{\pi \cdot R_{м}^{2} \cdot \vartheta_{ср}} = \frac{R_{н}}{R_{м}} \quad (14)$$

gde su $R_н; R_м$ poluprečnici cevi ishoda ispitivanja i industrijskih uzoraka; $\vartheta_{ср}$ je prosečna brzina protoka pumpe, m/s.

Koeficijent prenosa do industrijskog uzorka sa istim vrednostima parametara Re, β, H_1, $W_{Вok}$, ρ_o takođe mogu biti:

$$K_{s} = \frac{П_{р\,бн1}}{П_{р\,бм1}} = \frac{\mathrm{Re}\cdot \pi \cdot \cdot \vartheta_{ср} \cdot S_{прн} \cdot \sin\beta \cdot \sqrt{2g(H_1 + \frac{W_{вок}}{\rho_o g})}}{\mathrm{Re}\cdot \pi \cdot \cdot \vartheta_{ср} \cdot S_{прм} \cdot \sin\beta \cdot \sqrt{2g(H_1 + \frac{W_{вок}}{\rho_o g})}} = \quad (15)$$

$$= \frac{S_{прн}}{S_{прм}}$$

gde je $S_{пр}$- kapacitet ventila, m^2;

$W_{вок}$ – potiskivanje pomoću radnog klipa, mPa;

β – ugao otvaranja ventila;

ρ_o – prosečna gustina smeše betona i vlakana, m^3/kg;

H_1 – visina smeše betona i vlakana iznad ventila, m.

Prenos od ishoda ispitivanja do industrijskih uzoraka je moguć kada su *V*, ρ_o, k konstantni za oba tipa navedenih mašina.

$$K_{B} = \frac{П_{п\,н}}{П_{п\,м}} = \frac{\vartheta \cdot B_{н}^{2} \cdot \rho_{o}}{\vartheta \cdot B_{м}^{2} \cdot \rho_{o}} = \frac{B_{н}}{B_{м}} \quad (16)$$

gde je *v* brzina kaiša, m/s; B je širina kaiša, m.

Pretpostavlja se da je prenos od ishoda ispitivanja do industrijskih uzoraka za automatski rezač $\omega_н = \omega_м = \omega$ constant za oba tipa opreme, gde su $\omega_н$, $\omega_м$ ugaone brzine obrtanja noževa sečiva.

$$K_{м} = \frac{П_{ф\,н}}{П_{ф\,м}} = \frac{m_{фн} \cdot \omega_{н}}{m_{фм} \cdot \omega_{м}} = \frac{m_{фн}}{m_{фм}} \quad (17)$$

gde su $m_{фн}$, $m_{фм}$ mase isečenih sintetičkih vlakana koje se dopremaju iz automatskog rezača do mešalice za beton.

Stoga, da bi odredili koeficijent prenosa od ishoda ispitivanja do industrijskih uzoraka, mora se očuvati proporcionalnost između njegovih odvojenih komponenti.

Da bi se ispitao tehnološki komplet opreme, možemo izvršiti prenos prema sledećoj formuli:

$$K_{общ} = f(K_д, K_L, K_R, K_B, K_m) \quad (18)$$

Takav metodološki pristup omogućava prenos od ishoda ispitivanja (ukoliko ga ima) do industrijskih uzoraka tehnološkog kompleta opreme.

Navedene metode za postizanje efikasnog tehnološkog kompleta opreme pokazuju bitno poboljšanje radnih procesa i povećanje kvaliteta završnog proizvoda.

U poređenju sa tradicionalnom opremom, tehnološki kompleti zasnovani na efikasnim vrstama ovih novih mašina omogućuju sledeće:

- pripremu smeša pokretljivosti П = 4...10 cm i maksimalne veličine punjača 10...20 mm, smeše betona i vlakana i suvih smeša;
- uštedu vremena za pripremu građevinskih smeša za 15...20%;

- povećanje kapaciteta punjenja do 0,7...0,75;
- kombinovanje mešanja komponenti smeše;
- transport i malterisanje pomoću građevinskih smeša sa širokim opsegom mobilnosti (п = 6 ... 14 cm);
- ušteda snage za 15...20%;
- efikasnost betoniranja u ograničenim uslovima i na gradilištu i unutar objekata;
- povećanje mobilnosti trase transporta smeše za 1,2...1,5 puta
- maksimalna mehanizacija radnog učinka na gradilištu sa završenim gipsanim radovima.

4. ZAKLJUČAK

1. Mogućnosti upotrebe predloženog tehnološkog kompleta opreme.
2. Sistematski pristup analizi kompleta.
3. Konstrukscija i princip rada manipulatora za dopremanje smeše prilikom malterisanja zasnovano na matematici radi racionalne upotrebe. Algoritmi za određivanje koordinata brizgaljke.
4. Opis opreme za pripremu i transport smeše betona i sintetičkih vlakana na osnovu prenosa od ishoda ispitivanja do industrijskih uzoraka.
5. Prednosti novog tehnološkog kompleta u poređenju sa opremom koja se danas koristi.

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Universal Small-scale Equipment for Operations at the Construction Site

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Some infrastructure and residential objects are subject to destruction which requires for large-scale repair and restoration works. Under such conditions, the most vital issue is application of small-scale construction equipment which facilitates a complex performance of the whole cycles of works directly at the construction site. Vitality in creating new technological sets of small-scale equipment for construction sites and for certain scopes of their application is most important thing. It includes systematic approach to studying the proposed sets and results of investigating the transfer from test output to industrial samples. It shows efficiency of developing technological sets based on manipulators and combination of certain operations.

Keywords: small-scale, equipment, concrete, mixtures

1. INTRODUCTION

The small-scale equipment's are universal sets of equipment, since they are used (depending on certain conditions and technological peculiarities of work performance) with various equipment types included therein and mounted on the general foundation or frame. Such equipment types have been developed by the Department of Construction Process Mechanization of the Kharkov National University of Construction and Architecture (Ukraine).

The proposed sets are used in the following industries:

- Civil and industrial construction;
- Hydro technical construction;
- Reconstruction of buildings and structures;
- Off-form concreting of non-traditional buildings and structures;
- Concrete mixture preparation of various mobility and designation purpose;
- Use of equipment in casting industry for preparing the quick-hardening mixtures etc.
- Technological sets recommended for use at construction sites have been approved under:
- Preparation and transportation of concrete mixtures for various purposes, including dry and fiber-concrete mixtures with all the technological operations combined;
- Repair (restoration) works by means of wet shotcreting method at the most objects in Kharkov and other cities of Ukraine;

A scope of works, starting from preparation of construction mixtures (solutions) and finished by plaster operations. Technological sets consist of equipment types tested separately in the construction industry. Some examples are shown below.

2. PREPARATION OF MIXTURES FOR VARIOUS PURPOSES

Operation principle of such mixers is creation of complex may of mixture component particles in the machinery operating space under the fullness coefficient (*Кзо=0,7…0,8*) which facilitates intensive and quick mixing process. The following operating principles may be combined successfully: gravitational and forced mixing.

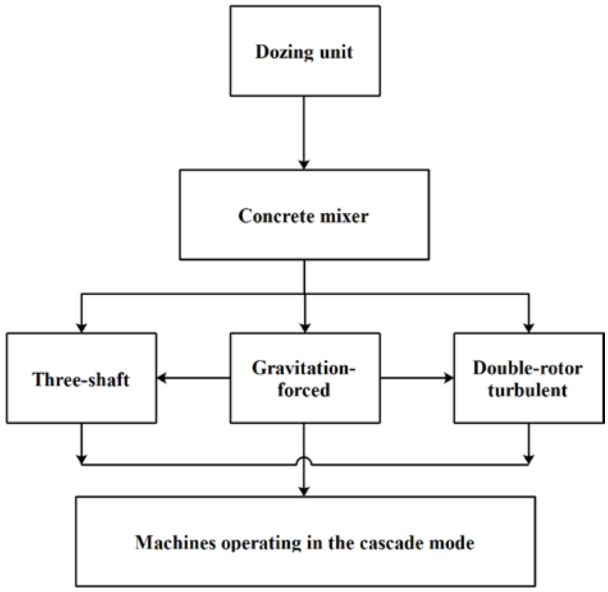

Fig. 1. The operation principle of mixing

3. PREPARATION OF MIXTURES AND THEIR TRANSPORTATION ALONG PIPELINES TO THE CONSUMER OR WORKING NOZZLE

All the operating machines and methods with the above sets involved have been patented in Ukraine.

Technological sets which include the aforesaid equipment are designated for works with capacity of $П_{техн}$

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= 3…5 m^3/h, for small scopes of work by wet shotcreting process under full mechanization of the whole cycle.

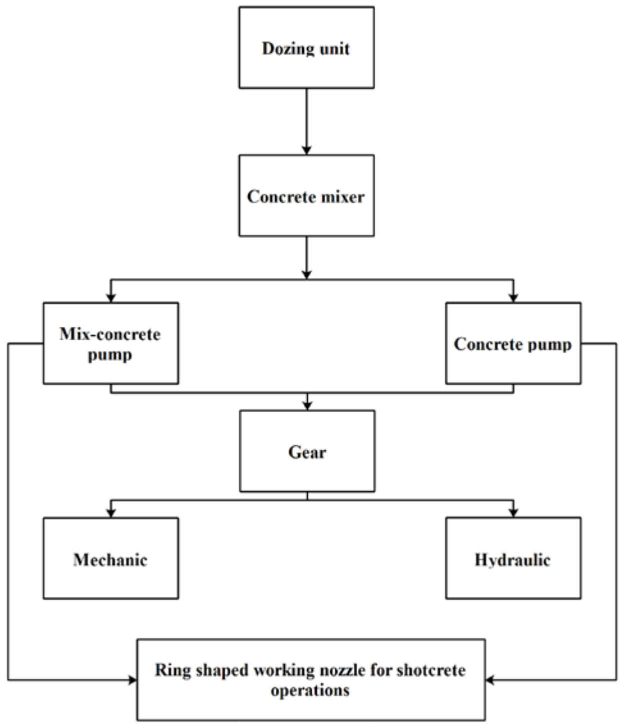

Fig. 2. The concrete mixing operation principle

The most reliable concrete pumps for that purpose are given on Fig. 3.

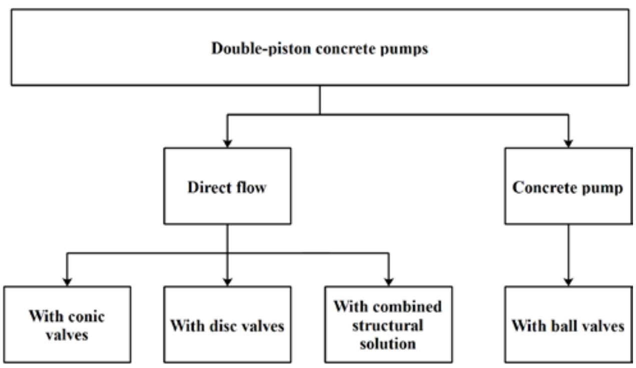

Fig. 3. The concrete pumps

Among all the best developed and tested concrete pumps, the direct flow concrete pump with spring-loaded conic valves (Fig. 4a) and the direct flow concrete pump with disc valves (Fig. 4b) are deemed as the most reliable and the most widespread [3]. In view of problems concerning shotcreting operations under the manual operating mode, there is a task to develop manipulator with software involved. [4]

Fig. 5 shows the proposed structure of small-scale manipulator which may be installed on the motor vehicle chassis and used for wet concreting operations. Manipulators provide the construction mixture supply to the working nozzle under concreting operations.

Manipulator has the following operating principle. Manipulator jib rotates around the axle [12] up to ± 90°.

Fig. 4. Double-piston direct flow concrete pumps
a) with conic valves;
b) with disc valves.

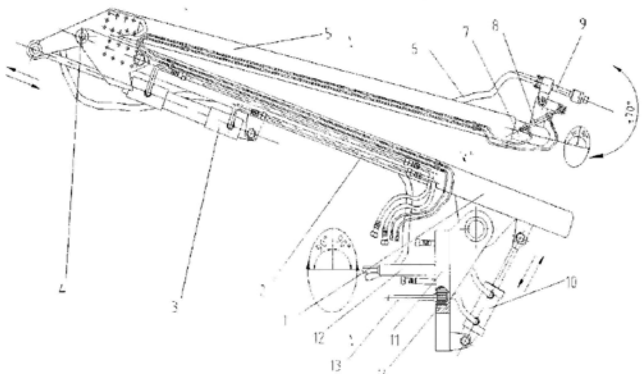

Fig. 5. Manipulator for construction mixture supply under concreting operations.
1 – Lower jib section; 2 – Rubber hose;3 – Hydraulic cylinder for lifting the upper jib section; 4 – Ball joint; 5 – Upper jib section; 6 – Material hose; 7 – Jib tip; 8 – Hydraulic cylinder for nozzle rotation; 9 – Working nozzle;10 – Hydraulic cylinder for lifting the lower jib section; 11 – Girth gear; 12 – Axle;13 – Power takeoff shaft; 14 – Small gear for jib rotation.

In order to increase the nozzle lifting height, lower jib section [1] moves up and down by means of hydraulic cylinder [10] in vertical position in the range of 95°, while upper jib section [5] rotates along ball joint [4] by means of hydraulic cylinder [3] in the range of 150°. Nozzle [9] moves up and down by means of hydraulic cylinder [8] in vertical position in the range of 70° and rotates by means of jib tip gear in the range of ± 90° in order to keep a right angle of concrete mixture jet against the shotcreted surface.

Manipulator operating goal means the nozzle even motion against the shotcreted surface. Two additional conditions shall be complied with:

- Permanent distance from nozzle section to the shotcreted surface;
- Nozzle perpendicular to the shotcreted surface.

With regards to random form of the shotcreted surface, it shall be treated as approximated elements, so it might be deemed as surface consisting of separate flat areas.

The prescribed distance of surface element to the shotcreted surface plane shall remain unchanged is the nozzle section (Point A_4, Fig. 6) is moved in the parallel plane at the prescribed distance. The second condition shall be complied with if the straight line moves through points A_3, A_4 (a nozzle in Fig. 6), orthogonally to the prescribed plane.

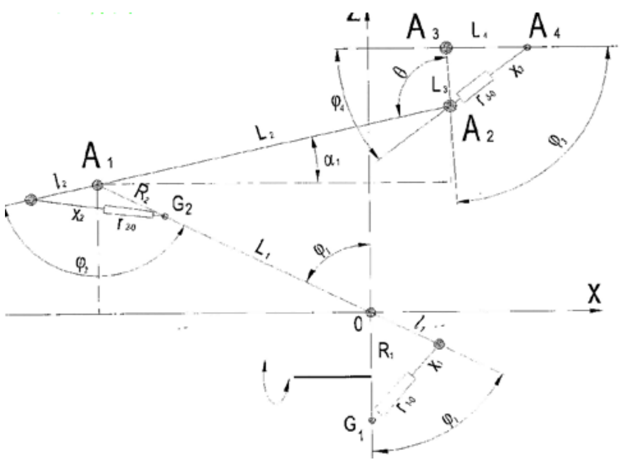

Fig.6. Scheme of determining the nozzle section coordinates at the manipulator

Nozzle section coordinates and nozzle axle direction are changed in the XOZ plane due to piston motion in hydraulic cylinders 1, 2, 3 (Fig.6).

Minimal distance from hydraulic cylinder pistons to the appropriate rotation axle (Fig. 6) is designated as $r_{1\text{-}0}$, $r_{2\text{-}0}$, $r_{3\text{-}0}$; piston stroke is designated as X_1, X_2, X_3; manipulator section length is designated as L_1, L_2, L_3, L_4. Rotation angle changes ϕ_1, ϕ_2, ϕ_3, ϕ_f in manipulator sections shall be determined under the formulas:

- Lower jib section against the rotation axle OZ

$$\varphi_1 = arccos\left\{\frac{R_1^2 + l_1^2 - (r_{1-0} + X_1)^2}{2R_1\, l_1}\right\} \quad (1)$$

- Upper jib section against lower jib section

$$\varphi_2 = arccos\left\{\frac{R_2^2 + l_2^2 - (r_{2-0} + X_2)^2}{2R_2\, l_2}\right\} \quad (2)$$

- Nozzle against upper jib section:

$$\varphi_3 = arccos\left\{\frac{L_3^2 + L_4^2 - (r_{3-0} + X_3)^2}{2L_3\, L_4}\right\} \quad (3)$$

$$\varphi_3 = arcsin\left\{\frac{L_3}{r_{3-0} + X_3}\sin\varphi_3\right\} \quad (4)$$

Coordinate points in the ZOX plane shall be determined depending on:

- point A_1:

$$\begin{cases} X_{A_1} = -L_1\, sin\varphi \\ Z_{A_1} = L_1\, cos\varphi \end{cases} \quad (5)$$

- point A_2:

$$\begin{cases} X_{A_2} = L_2 \sin(\varphi_2 - \varphi_1) - L_1\, sin\varphi_1 \\ Z_{A_2} = L_1\, cos\varphi_1 - L_2 \cos(\varphi_1 - \varphi_2) \end{cases} \quad (6)$$

- point A_3:

$$\begin{cases} X_{A_3} = X_{A_2} - L_3 \sin\left(\frac{\pi}{2} + \varphi_1 - \theta\right) \\ Z_{A_3} = Z_{A_2} + L_3 \cos\left(\frac{\pi}{2} + \varphi_1 - \theta\right) \end{cases} \quad (7)$$

- point A_4:

$$\begin{cases} X_{A_4} = X_{A_2} + (r_{3-0} + X_3) cos\varphi_4 \\ Z_{A_4} = Z_{A_2} + (r_{3-0} + X_3) sin\varphi_4 \end{cases} \quad (8)$$

Under the manipulator rotation against axle [12] the Z and Y coordinates of its location get changed. Under the jib rotation, location of the manipulator lower section rotation point gets changes. In such cases the reference point shall be located in another place, such as girth gear center. In the new coordinate system:

$$X_0 = X_i + X_{\text{ц}};\ Y_0 = (Z_i + Z_{\text{ц}})\cos\varphi \quad (9)$$

where φ means jib rotation angle.

In such case the following equation for shotcreted surface description shall apply:

$$AX_0 + BY_0 + CZ_0 + D = 0 \quad (10)$$

The above research resulted in making up the algorithm which may determine piston stroke value in each hydraulic cylinder used for operating each jib section which may facilitate regular motion of working nozzle parallel to the shotcreted surface, under its strict location perpendicular thereto (Fig.7).

So the algorithm shown in Fig. 7 provides an opportunity for software development for operating the wet shotcreting process by means of computers.

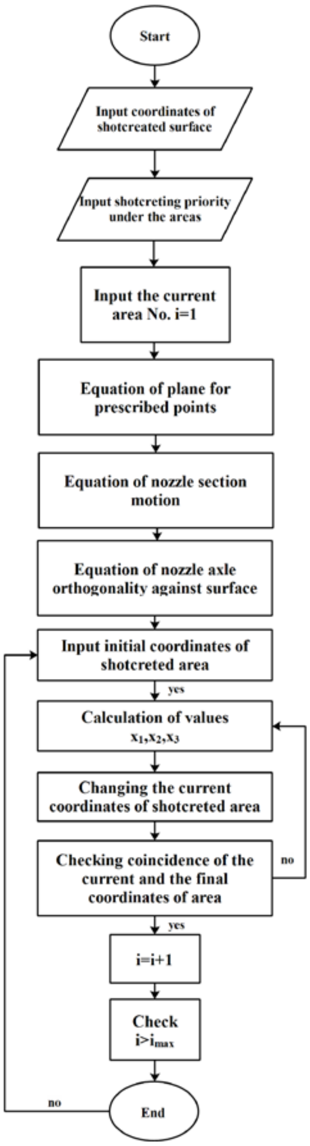

Fig.7. The algorithm for software development for operating the wet shotcreting process

4. PREPARATION AND TRANSPORTATION OF CONCRETE MIXTURES WITH SYNTHETIC FIBERS

Technological set of small-scale equipment is shown in Fig. 8. [5]. This set of equipment has the following operating principle. Dry components of fiber-concrete mixture are supplied from the belt feeder [1] bunker [2] to the belt and then are transported to the three-shaft concrete mixer [4].

At the same time fibers cut by the automatic carver [3] are supplied. In the mixer left zone the dry components get mixed with fibers, while in the right zone dry fiber-concrete mixture correlates with water.

If necessary, the final fiber-concrete mixture is supplied from the right zone to the concrete pump with disc valves [5] and then is transported either to the consumer or to the working nozzle for shotcreting operations.

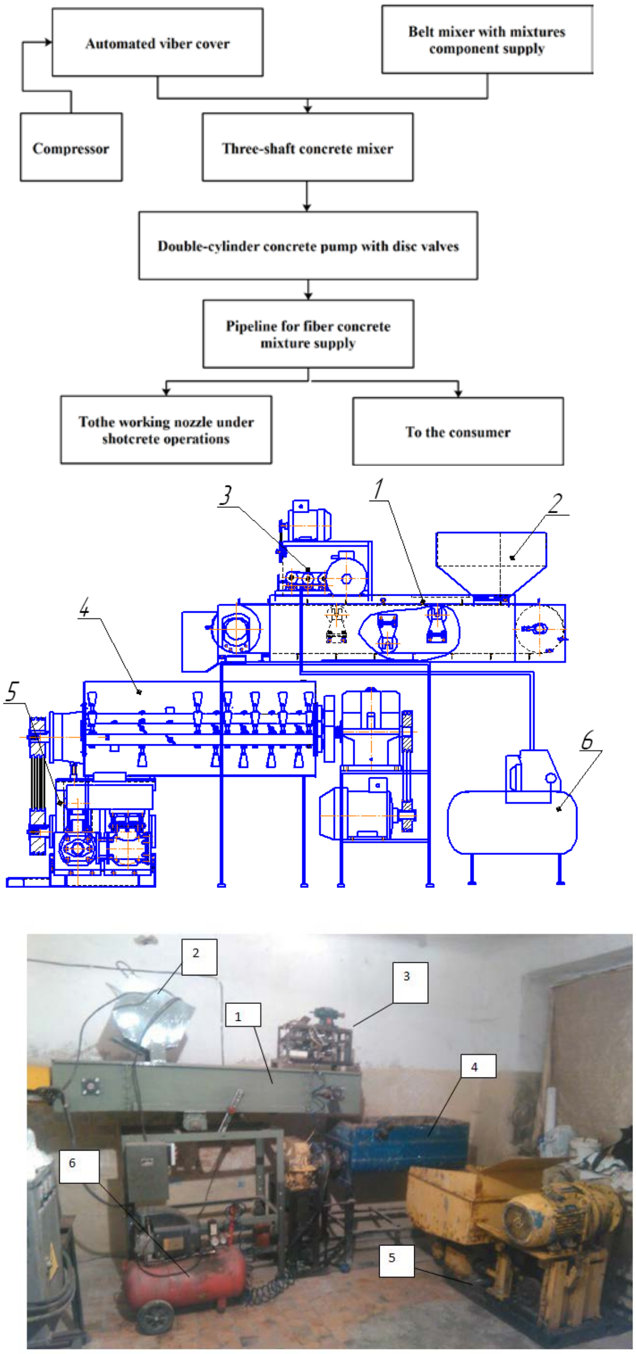

Fig.8. Technological set of small-scale equipment
a) principal scheme of the technological set of equipment
b) general view of the technological set of equipment
1 – Belt feeder; 2 – Belt feeder bunker; 3 – Synthetic fiber carver; 4 – Three-shaft concrete mixer; 5 – Concrete pump with disc valves; 6 – Compressor

So the whole operating process may take place at the construction site with all the operations combined, from cutting the synthetic fibers and to the final fiber-concrete mixture supply.

Transfer from test output to industrial samples applies to the whole technologically set of equipment, starting from concrete mixer.

In case of hydrodynamic similarity between test output and industrial samples of concrete mixers, the following conditions shall be taken into account: mixtures shall be prepared in machines with the same density, dynamic and cinematic viscosity parameters.

In such case the Reynolds number equation shall apply:

$$\mathrm{Re}_{н} = \mathrm{Re}_{м} = idem \qquad (11)$$

$$\left\{ \mathrm{Re}_{н} = \frac{\rho_0 \cdot v_{н} \cdot D_{н}}{2}; \mathrm{Re}_{м} = \frac{\rho_0 \cdot v_{м} \cdot D_{м}}{2}, \right. \qquad (12)$$

where:

- $Re_{н}$, $Re_{м}$ mean, respectively, values for test output and industrial samples of equipment;
- $v_{н}$, $v_{м}$ mean, respectively, rotation speed for operating elements of test output and industrial samples of mixers;
- $D_{н}$, $D_{м}$ mean diameters of operating elements of test output and industrial samples of machinery.

If we apply, $v_{н}$, $v_{м}$ with regards to their angular speeds, for hydrodynamic similarity of machinery, it is necessary to provide that

$$\omega_{н} = \omega_{м} \cdot K_{Д}^{-2}$$

where $\omega_{н}$, $\omega_{м}$ mean, respectively, angular rotation speeds of operating mixers, while $K_{Д}$ means scale coefficient of transfer.

Hereby the determinant minimum dimensions of concrete mixers are diameter of operating element under the blade tip (D) and its length (L). For the present types of concrete mixtures, the condition

$$\frac{L_{м}}{L_{м}} = \frac{L_{н}}{L_{н}} = idem = m$$

shall apply, where m means numeric value changing the equipment parameters in the process of scale transfer.

Transfer from test output to industrial samples by means of geometric scale of changing productivity $П_{н}$, as compared to $П_{м}$, shall be treated as follows:

$$\frac{П_{н}}{П_{м}} = \frac{V_{н}}{V_{м}} \cdot \frac{\omega_{н}}{\omega_{м}} = K_{Д}^{2} \cdot K_{L} \cdot \frac{1}{K_{Д}^{2}} = K_{L} \qquad (13)$$

where $v_{н}$, $v_{м}$ mean operating volumes of the appropriate fiber-concrete mixture; therefore

$$K_{L} = \frac{L_{н}}{L_{м}}$$

means scale transfer from test output to industrial sample of concrete mixer included into the technical set of equipment. Transfer of other equipment included into the technical set of equipment operating with fiber-concrete mixtures has the similar form.

Scale coefficient for transfer to industrial sample of concrete pump shall be determined under the formula:

$$K_{R} = \frac{П_{рбн}}{П_{рбм}} = \frac{\pi \cdot R_{н}^{2} \cdot \vartheta_{ср}}{\pi \cdot R_{м}^{2} \cdot \vartheta_{ср}} = \frac{R_{н}}{R_{м}} \qquad (14)$$

where $R_{н}$, $R_{м}$ mean, respectively, radii of pipeline test output and industrial samples, m; $\vartheta_{ср}$ mean average flow speed under the current supply by means of concrete pump, m/s.

Scale coefficient for transfer to industrial sample under the same values of parameters Re, β, H_1, $W_{вок}$, ρ_o may be also the following:

$$K_{s} = \frac{П_{рбн1}}{П_{рбм1}} = \frac{\mathrm{Re} \cdot \pi \cdot \cdot \vartheta_{ср} \cdot S_{прн} \cdot \sin\beta \cdot \sqrt{2g(H_1 + \frac{W_{вок}}{\rho_o g})}}{\mathrm{Re} \cdot \pi \cdot \cdot \vartheta_{ср} \cdot S_{прм} \cdot \sin\beta \cdot \sqrt{2g(H_1 + \frac{W_{вок}}{\rho_o g})}} = \qquad (15)$$

$$= \frac{S_{прн}}{S_{прм}}$$

where:

$S_{пр}$ means valve capacity, m^2;

$W_{вок}$ – discharge by means of operating piston, mPa;

β – valve opening angle;

ρ_o – average density of fiber-concrete mixture transportation, m^3/kg;

H_1 – fiber-concrete mixture height above the valve, m.

Transfer from test output to industrial samples is allowable when V, ρ_o, k is constant for both types of reviewed machines.

$$K_{B} = \frac{П_{пн}}{П_{пм}} = \frac{\vartheta \cdot B_{н}^{2} \cdot \rho_o}{\vartheta \cdot B_{м}^{2} \cdot \rho_o} = \frac{B_{н}}{B_{м}} \qquad (16)$$

where v means belt speed, *m/s*; B means belt width, *m*.

Transfer from test output to industrial samples for the automatic carver supposes that $\omega н = \omega м = \omega$ constant for both types of equipment, where $\omega н$, $\omega м$ mean, respectively, angular rotation speeds of blade cutters.

$$K_{м} = \frac{П_{фн}}{П_{фм}} = \frac{m_{фн} \cdot \omega_{н}}{m_{фм} \cdot \omega_{м}} = \frac{m_{фн}}{m_{фм}} \qquad (17)$$

where $m_{фн}$, $m_{фм}$ mean, respectively, masses of carved synthetic fibers supplied to the concrete mixer from automatic carver.

Therefore, in order to determine scale coefficient of transfer from test output to industrial samples, preservation of proportionality between its separate components shall be mandatory.

In order the study the technological set of equipment, we may perform transfer under the following formula:

$$K_{общ} = f(K_{д}, K_{L}, K_{R}, K_{B}, K_{m}) \qquad (18)$$

Such methodological approach provides an opportunity of transfer from test output (if any) to industrial samples of the technological set of equipment.

The aforesaid methods of creating effective technological sets of small-scale equipment show the methods of essential improvement of the operating processes and increase of the final product quality.

As compared to traditional equipment, the technological sets based on effective types of tested new machinery provide the following:

- Preparation of mixtures with mobility П = 4...10 cm and maximal filler size of 10...20 mm, fiber-concrete and dry construction mixtures/solutions;
- Time saving for preparation of construction mixtures by 15...20%;
- Increase of the operating volume filling rate up to 0,7...0,75;
- Combination of mixing the mixture components and their activation;
- Transportation and shotcreting operations by means of construction mixtures with wide mobility range (п = 6 ... 14 cm);
- Power saving by 15...20%;
- Effectiveness of concrete operations under restricted conditions both at the construction site and inside buildings;
- 1,2...1,5-fold increase of low mobility mixture transportation route;
- Maximum mechanization of work performance at the construction site with finished plaster operations.

5. CONCLUSION

1. Scopes of using the proposed technological sets of equipment.

2. Systematic approach to the set analysis.

3. Structure and operating principle of manipulator for mixture supply under shotcreting operations, under mathematical grounds for its rational use. Algorithms of determining the nozzle section coordinates.

4. Description of small-scale equipment for preparation and transportation of fiber-concrete mixtures with synthetic fibers, on the grounds of transfer from test output to industrial samples.

5. Advantages of new technological sets against the widespread active equipment.

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