Automatic Control of the Concrete Mixture Homogeneity in Cycling Mixers

Tikhonov Anatoly Fedorovich¹, Anatoly Drozdov¹

¹National Research Moscow State University of Civil Engineering, 129337, 26, Yaroslavskoye Shosse, Moscow, Russia

Abstract. The article describes the factors affecting the concrete mixture quality related to the moisture content of aggregates, since the effectiveness of the concrete mixture production is largely determined by the availability of quality management tools at all stages of the technological process. It is established that the unaccounted moisture of aggregates adversely affects the concrete mixture homogeneity and, accordingly, the strength of building structures. A new control method and the automatic control system of the concrete mixture homogeneity in the technological process of mixing components have been proposed, since the tasks of providing a concrete mixture are performed by the automatic control system of processing kneading-and-mixing machinery with operational automatic control of homogeneity. Theoretical underpinnings of the control of the mixture homogeneity are presented, which are related to a change in the frequency of vibrodynamic vibrations of the mixer body. The structure of the technical means of the automatic control system for regulating the supply of water is determined depending on the change in the concrete mixture homogeneity during the continuous mixing of components. The following technical means for establishing automatic control have been chosen: vibro-acoustic sensors, remote terminal units, electropneumatic control actuators, etc. To identify the quality indicator of automatic control, the system offers a structure flowchart with transfer functions that determine the ACS operation in transient dynamic mode.

1. Introduction

Technological requirements to the quality of dosing in the production of concrete mixtures are determined by the need to ensure the consistency of the specified properties of mixtures, such as homogeneity. The concrete mixture homogeneity is a percentage according to the given composition of components. The mix is considered homogeneous if the samples taken from different places in the mixer contain the individual components of the mixture in equal percentages. The concrete mixture homogeneity is associated with the strength of concrete and, accordingly, building structures and directly depends on the correction of water supply to the cyclical mixer while mixing components in it [1, 2].

It has been established that the correlation between the mixing components and the dosed quantity of water on which the water-cement ratio (\(W/C\)), and therefore the mixture homogeneity depends, is not maintained due to the variable moisture content of aggregates, and especially sand [3, 4].

Practice has shown that the introduction of the known devices for automatic control of the concrete mixture homogeneity during the mixing of components (by changing the current of the mixer motor, monitoring the electrical conductivity of the concrete mixture depending on the amount of water contained in it, monitoring the moisture content of aggregates with neutron moisture meters) does not ensure the desirable homogeneity of the concrete mixture (the error is up to 30%), because of the...
imperfection of the devices for controlling the mixture homogeneity and the associated mixing time of the components [5]. Therefore, the production requires efficient and reliable automatic devices that allow to determine the amount of unaccounted moisture in inert aggregates based on modern computer equipment and, accordingly, promptly adjust the consumption of the water batcher, which ensures the desired homogeneity of the mixture and the optimal mixing time of components, which is related to the productivity of the cyclic concrete mixer [6].

2. Study methodology

Concrete mixture is a compound mass containing fine cement particles, coarse aggregate grains, water and air involved in the process of preparing the mixture [7]. During mixing in the mixer, component particles are given a whirling motion, thus causing friction and collision forces between the particles, the body and the blades of the mixer, which creates elastic modes, leading to the body vibration and the generation of vibroacoustic signals. With the introduction of a controlled dose of water into the mixer, the cement paste gradually converts from the elastic medium into a viscoelastic one with the passage of time of the process of mixing components, which affects the characteristics of vibrational and, accordingly, electric acoustic signals that are functionally related to a change in the concrete mixture homogeneity [8].

The theoretical studies have constituted a ground for the development of an adaptive (with fuzzy logic) automatic control system for the concrete mixture homogeneity, taking into account the previously unknown environmental perturbations $F_{ENV}$: variable humidity of inert aggregates, mixing time of components and their grain size composition, a set of variable mix formulation depending on the type of construction, wear of rotating blades of the mixer, bearing friction of the mixer drive, etc. [9, 10].

The mixing time of the components in the mixer will be a variable unknown value along the mixture homogeneity, which depends on environmental influencing factors $F_{ENV}$. The main control device $CD_M$, together with the control object $CO$, is a conventional non-adaptive automatic system (connection 1 – opening of the mixture discharge gate $Y_2$ after the specified mixing time and switching on the mixer drive $M$). The adaptation control device $CD_A$ constantly adjusts the operation of the $CD_M$ by regulating the water supply of the valve $Y_1$, depending on the concrete mixture homogeneity, the parameters of which are controlled by vibro-acoustic sensors VAS1 ... VAS4. Signals from these sensors arrive at the $CD_A$ through the RTU and in this case the correction circuit 2 is connected. When the optimum mixture homogeneity is reached, a command is made to open the gate of the concrete mixer $Y_2$, which indicates the readiness of the dose (figure 1).

**Figure 1.** Structure of the elements of the adaptive system for automatic control of the concrete mixture homogeneity with the operational correction of the water supply in a concrete mixer.
VAS1...VAS4 – vibro-acoustic sensors; CD_M – main control device; CD_A – adaptation control device; CN – controller of concrete trademark and minimum mixing time; RTU_IN, RTU_OUT – remote terminal unit – input and output; Y1 – actuator for correcting the water supply to the concrete mixer; Y2 – actuator for discharging the mixture when homogeneity is achieved; M – mixer motor; MPC – microprocessor controller; F_ENV – environmental perturbations; CO – control object.

To obtain the dependence of the root-mean-square value of vibration accelerations as a function of the mixing time when the homogeneity changes, it is necessary to simulate this process based on the following perturbing factors: change of humidity variable from 0 to 18%, different grades of concrete mixture (100, 200, 300, 400, 500), taking into account the wear of the rotating blades to 65% and bearing friction of the mixer drive with CPR=0.86. To this end, a structure flowchart of the automatic control system ACS of the concrete mixture homogeneity during its mixing in a concrete mixer has been created, which shows the transfer functions of all system elements in accordance with the structure in (figure 2).

**Figure 2.** Structure flowchart of the ACS of the concrete mixture homogeneity.

\[
W_1(p) = F_1, \quad W_2(p) = \frac{V_D}{V_0} = F_2, \quad \text{controller; } W_6(p) = \frac{V_T}{V_0} = F_4, \quad \text{reference element; }
\]

\[
W_3(p) = \frac{F_{MP}(T_{M}+1)}{T_{M}} \quad \text{– microprocessor controller; } W_4(p) = \frac{F_{AC1}}{T_{AC1}+1} \quad \text{– water control valve; } W_5(p) = \frac{1^+p}{T_{c}p+1} \quad \text{– mixer; } W_6(p) = \frac{F_{AC2}}{T_{AC2}+1} \quad \text{– discharge gate of the ready mixture; }
\]

\[
W_7(p) = \frac{F_{VAS}}{T_{VAS}+1} \quad \text{– vibroacoustic sensor; }
\]

\[
W_0(p) = \frac{W_1(p)W_2(p)W_3(p)W_4(p)W_5(p)W_6(p)W_7(p)}{1+W_1(p)W_2(p)W_3(p)W_4(p)W_5(p)W_6(p)W_7(p)} \quad \text{– general transfer function of ACS elements; }
\]

T_0 – mixing time of the mixture components specified by the operator; T_OPT – optimal mixing time, determined by homogeneity; F_{AC1}, F_{AC2} – air cylinder gain factors; \tau – delay time; C_{VAS} – conversion coefficient of vibroacoustic signals into electrical; \sigma – mixer body vibration frequency; T_{MP}, T_{AC1}, T_{AC2}, \tau, T_{VAS} – element time constants; F_P, F_{ENV} – operator-controlled external influence.

3. Discussion

By setting different values of the transfer functions of individual elements \(W_i(p)\), the necessary quality parameters of the ACS regulation are achieved in the transient dynamic mode by mathematical modeling of the technological process of mixing concrete mixture components in the expression \(W_0(p)\).

The operator provides information on the trademark of the ready concrete mixture, its required volume and the minimum mixing time through the input device (controller). The microprocessor controller takes the required mix formulation from the data bank and calculates the mass of each component without taking into account the actual moisture content of the aggregates. In this case, the supply of water by the main batcher to the mixer is 15-20% less than the preset one according to the formulation, which allows to take into account the moisture content of the aggregates. As the mixture reaches the optimum value in accordance with the homogeneity controlled by the vibro-acoustic sensors, water is added (by the valve \(\gamma_1\)) directly to the mixer during the mixing until the dose is ready.

The vibro-acoustic sensors with the static characteristic convert the vibrations of the mixer body into an electrical signal that will be a variable depending on the readiness of the dose determined by
the vibration frequency of the mixer body. When the concrete mixer is idling (not loaded with components), the voltage from the vibration sensors during the time T will be a constant value. Experimental studies have shown that when the mixer is filled with components, the direct dependence of the points 1-2 during the mixing time turns into a broken curve (p. III – p. IV, figure 3). In this case, the nature of the change in the curve III-IV, and hence the output voltage $U_{OUT}$, depends on the time of arrival of each component in the concrete mixer.

The nature of the dependence $U = f(T)$ (figure 3) reflects the technological process of preparing the mixture from the loading of components to the delivery of the ready mixture, taking into account the changes in vibroacoustic signals determining the degree of optimization of homogeneity, and hence the mixture readiness.

![Figure 3. Dependence of the output voltage on the vibration acceleration of the mixer body during the mixing time of the concrete mixture components.](image)

1, 2 – idling mode of mixer motor operation;
3...5 – mode of loading and simultaneous mixing of the mixture components;
A – regulation of the mixture homogeneity by supplying water to the mixer;
B – mixing of components with homogeneity control;
C – readiness of the mixture and the command to open the mixer gate $γ_2$ to discharge the concrete mixture into vehicles.

In the idle mode of the mixer (not loaded), $U_{OUT}$ varies in the range of points 1 ... 4 (figure 3), and when mixing sand (it pours first) and crushed stone (it pours second), the vibration intensity rises sharply (section 4-5) and reaches the value of p. III. When loading cement (it pours third) and mixing with sand and crushed stone, $U_{OUT}$ decreases (section 4-5), which can be attributed to the damping of elastic vibrations by the cement. When water is supplied, $U_{OUT}$ again increases (section A), and then begins to decrease sharply (section B), which characterizes the process of cement paste formation and gradual conversion of the medium from elastic to viscoelastic. After a while (about 45 seconds after loading all components, including water), the decrease in the value of the $U_{OUT}$ stops and a steady-state vibration mode is established, which corresponds to obtaining the mixture homogeneity and ending the mixing process. At the same time, a command is made to open the gate $γ_2$ to discharge the ready concrete mixture into vehicles.

4. Conclusion
The results confirm the possibility of determining the concrete mixture homogeneity and the optimal duration of mixing by measuring the characteristics of the oscillatory field of the mechanical system: mixer – a concrete mixture and can be used for the development of corresponding measuring and controlling devices in establishing the microprocessor control system of concrete mixture and solution technologies in mobile installations and central plants for the production of building structures.

References
[1] Korolev K M 1996 Intensification of the preparation of concrete mix Moscow: Stroiizdat 144.
[2] Kaiser L A, Levin L I 1992 Technological fundamentals of automatic correction and optimization of the concrete mix composition Moscow: Stroyizdat, 182.

[3] Korolev K M, Malinina L A 1998 Actual questions of automation of processes of preparation of concrete mixes Moscow: NIIZhB, 130.

[4] Berkut A I, Zakharov Ya V, Goryunov I I 2002 Experimental study of the process of preparation of building mixtures for optimization purposes Moscow: MGSU, 1 54.

[5] Tikhonov A F 1997 Device for continuous control of uniformity of a freshly prepared concrete mix Report on research work Moscow: TsNIIOmTP, 78.

[6] Gayle J B, Lacey P M, Gary J H 1997 Ind. Eng. Chem. so. 1279 1997.

[7] RulnovA A, Makarova E V 2000 Automation of the continuous process of mixture formation on the basis of metering-flow integrators 2000 Moscow: Higher educational institutions herald "Construction", 7 31.

[8] Khayutin Yu G, Levy E B, Sovalkov I G 2003 Statistical analysis of the uniformity of a concrete mixture Moscow: Stroiizdat, 192.

[9] Tikhonov A F 1996 Automation of quality control of products made of concrete and reinforced concrete Moscow: Stroiizdat, 300.

[10] Weidenbait S S 1998 Advances in chemical Engineering, II Academic Press, New York.