Parameters Variation of The Elastic Arm-Blade System Vibration Movement at The Planetary Mixers to Improve the Homogenization Process

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Abstract:-The high performance of the planetary mixers with two vertical axis is closely related to the degree of prepared concrete homogenization. The freshly concrete homogenization process is influenced by the blades vibrational movements because of the alternative bending of the mixer arm, shaped like an embedded elastic beam. In order to homogenization process mathematical modelling, the case of a planetary mixer with a capacity of 2.5 m^3 is considered, for which the bending forces and arrows, the own pulsations, as well as the amplitudes of the oscillating movement were analyzed in three cases. In order to make the mixing more efficient, the constructive shape, the resistance module and implicitly the stiffness of the arm-blade system are successively modified, aiming to obtain proper pulsations as close as possible to the excitation pulsations of the system and implicitly with movement amplitudes as high as possible in conditions of maintaining high reliability. The paper therefore aims an analysis of the parameters variation of the arm-blade system vibration movement depending on its elasticity, in order to improve the homogenization process for planetary mixers with two vertical axis.

Keywords: - mixer, concrete, elastic beam, vibrations, arm-blade

1. INTRODUCTION

Planetary mixer arm-blade system can be considered viscoelastic element with a single degree of release. The arm-blade system movement can be considered a viscous damping system forced vibration, subjected to harmonic excitations [1,2].

The planetary mixer arm can be assimilated with an embedded elastic beam [10,12], subjected to the bending actions, as a result of all the concrete masses in front of the blade and the arm portion inside the concrete, to which are added the own masses of the blade and the arm, reduced at its end. There are two main bending actions, corresponding the two systems movements (the two working rotations), during the “planetary mixing”[19].

During the kneading process, on each mixer arm-blade system acts the harmonic force

$$F_i = F_{0i} \sin \omega t = F_{01i} \sin\omega_1 t + F_{02i} \sin\omega_2 t$$

in which $F_0 = F_{01} + F_{02}$ represents the force amplitude (maximum bending force) for the blade i, and ω represents the pulsation arm-blade system, given by the rotation speeds of the mixer ω_1 and ω_2, in a stable regime [6,13].

The vibrational process can be mathematically modelled by determining the bending arrows, its own pulsations, the elastic constants and the resulting oscillating motion amplitudes, for each arm-blade system of the planetary mixer [7].

The homogenization efficiency of the mixture is considered much better if the blades pulsations have values closer to the two excitation pulsations (of the central rotor ω_1 and of the each blades rotor ω_2) and the movement amplitudes are higher [8-13].

Ensuring these requirements is conditioned by the degree of the arm-blade systems elasticity, the superior systems stiffness ensuring increased reliability in homogenizing high consistency degree concrete, while leading to the mixing performances decrease in the case of fluid concrete, with strength classes lower [14-18].

In order to improve the system elasticity, the mixer arm can be successively modified, both in shape and diameter, resulting smaller resistance modules, pulsations closer and closer to the two rotors pulsations and higher and also higher movement amplitudes[7].

The calculations performed in three consecutive cases for each arm-blade system constructive variant, followed by the movement amplitudes graphical representation have to highlight : the movement amplitudes according to the arm-blade systems own pulsations, the pulsations values corresponding to the maximum systems amplitudes, and the reporting of the arm-blade systems pulsation values, to the values of the two excitation pulsations (the one of the central rotor and blades own rotors pulsation).

This study is accomplished for the field of use for concrete planetary mixers with different useful capacities. It may be considered as a starting point for all mixers with vertical axis research, from point of view of the target homogenization degree, taking into account the mixing energy consumption.

2. MATHEMATICAL MODELLING OF THE HOMOGENIZATION PROCESS AT THE PLANETARY MIXER

2.1 Determination of arm-blade systems bending arrows for planetary mixer

For the planetary mixer with two vertical axis shown schematically in figure 1, the arm-blade system is considered as an embedded elastic bar and subjected to bending with composite force F (figure 2), resulting as an effect of the concrete masses in front of the blade and the arm portion inside the concrete, to which are added the own masses of the blade and of the respective arm portion [10-12].

The total bending mass of the arm-blade system at the mixer shown in figure 1 (for example for the left group of blades 1-3) can be determined with the relation:

$$M_1 = m_b + m_a + m_1 + m_2, \qquad (1)$$

in which:

-m_b is the blade mass;

-m_a is the mass of the arm portion inserted into the material;

-m_1 represents the sum of concrete masses in front of the blade, during the "planetary" mixing process, corresponding to radiuses R_{1i} , R_{2i}.

$$m_1 = m_{11} + m_{12} \qquad (2)$$

-m_2 represents the sum of concrete masses in front of the blade arm during the "planetary" mixing process, corresponding to radiuses R_{1i} , R_{2i}.

$$m_2 = m_{21} + m_{22} \qquad (3)$$

The calculation relations for determining the four masses are as follows:

$$m_p = q_m \text{x} S_p \text{x} g_p \qquad (4)$$

where: S_p și g_p represent the surface and the thickness of the blade, and q_m the density of material (steel);

$$q_m = 7{,}85 \text{ kg/dm}^3$$

$$m_b = (h_m - h_p) \text{x} \frac{\pi d^2}{4} \text{x} q_m \qquad (5)$$

in which: h_m is the concrete layer height in the mixer, h_p is the blade mixer height and d is the mixer arm diameter;

$$m_1 = S_p \text{x} q_b \text{x } 2\pi \text{ x } (R_{1i} + R_{2i}) \qquad (6)$$

in which: q_b is the density of fresh concrete and R_{1i} , R_{2i} are the radiuses of the blade i;

q_b= 2200 kg/m^3.

$$m_2 = (h_m - h_p) \text{x} \frac{\pi d}{2} \text{x } 2\pi \, (R_{1i} + R_{2i}) \text{ x} q_b \qquad (7)$$

a) Calculation of angular deformation and maximum arrow [10-12]

For the case of the arm-blade system considered as an embedded beam of length l, subjected to the action of force F produced by the bending masses (figure 2), the maximum angular deformation and the maximum arrow are determined by applying the following equation:

$$EI_z \frac{df}{dx} = EI_z \varphi = \int Fx dx + C_1 = \frac{Fx^2}{2} + C_1 \qquad (8)$$

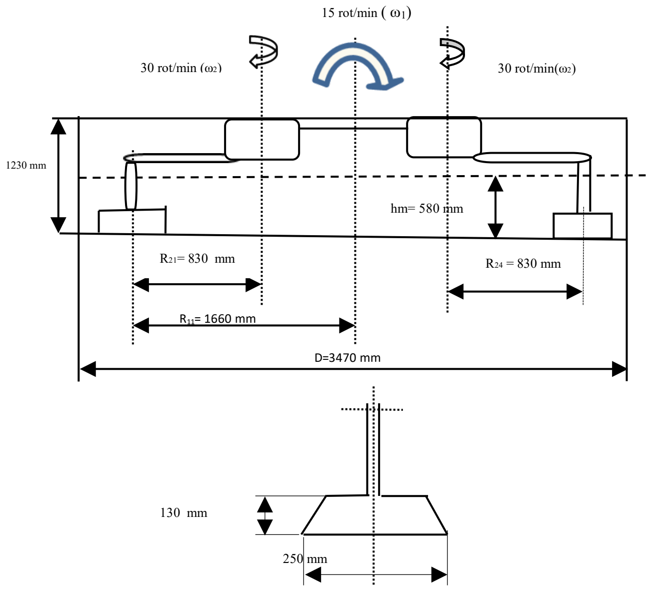

Figure 1. Planetary mixer of 2.50 m^3, schematic representation

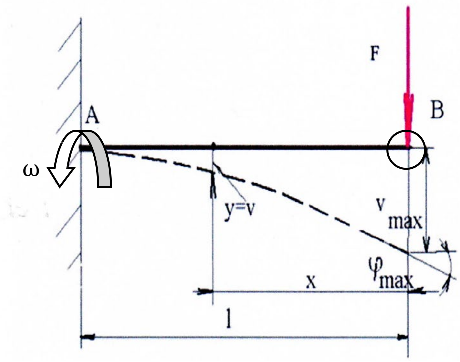

Figure 2. The arm-blade system, assimilated with an embedded elastic beam

The integration constant is determined from the boundary condition x=l, φ=0, that is it results

$$C_1 = -\frac{Fl^2}{2} \qquad (9)$$

Angular deformation φ can be written like this:

$$\varphi=\frac{1}{EI_z}\left(\frac{Fx^2}{2}-\frac{Fl^2}{2}\right) \quad (10)$$

Maximum rotation (angular deformation) occurs in the embedding, for x=0:

$$\varphi_{max}=\frac{Fl^2}{2EI_z} \quad (11)$$

b) Maximum deflection calculation [10]

Integrating relation (8) we have:

$$EI_z v=\int\left(\frac{Fx^2}{2}-\frac{Fl^2}{2}\right)dx+C_2=\frac{Fx^3}{6}-\frac{Fl^2x}{2}+C_2 \quad (12)$$

The integration constant is determined from the boundary condition x=l, ν=0

$$0=\frac{Fl^3}{6}-\frac{Fl^2}{2}+C_2,$$

from which $C_2=\frac{Fl^3}{3}$ (13)

The deflection can be expressed like this:

$$f=v=\frac{1}{EI_z}\left(\frac{Fx^3}{6}-\frac{Fl^2x}{2}+\frac{Fl^3}{3}\right) \quad (14)$$

The maximum arrow occurs at the free end, for x=0:

$$v_{max}=f=\frac{Fl^3}{3EI_z} \quad (15)$$

2.2 The parameters of forced vibrations

Characteristic physical sizes are:
- maximum deflection of the arm-blade system:

$$f=\frac{Fl^3}{3\,EI}$$

- disturbance force: $F_i = M_i\omega_i^2 f_i$ (16)
- elastic constant of the system: $k_i = M_i\omega_i^2$ (17)
- own pulsation: $\omega_i = \sqrt{\frac{g}{f_i}}=\sqrt{\frac{3EI}{M_i {l_i}^3}}$, (18)

in which: M_i is the total bending mass (sum of the masses) and l= R_{2i} (radius) for each blade, E – the modulus of elasticity of the steel E= 2,1 x 10^5 N/mm^2, and I=I_z - is the axial modulus of resistance, determined with the relation:

$$I=\frac{\pi d^4}{64}, \quad (19)$$

in which d is the diameter of mixer arm.

For each blade we consider the harmonic forces $F_i= F_{0i}\sin\omega t$, and the force amplitude for the blade i, is $F_{0i} = M_i$g in which M_i represents the total bending mass, calculated with relation (1).

The amplitude calculation formula for each blade is as follows [1]:

$$A_i=\frac{M_i\omega_i^2 f_i}{\sqrt{(k_i-M_i{\omega_i}^2)^2+{c_i}^2{\omega_i}^2}} \quad (20)$$

where we have:

$$c_i= 2\xi\sqrt{k_iM_i} \quad (21)$$

in which ξ= 0,2 is the viscoelastic system damping factor [1].

3. DYNAMIC MODELLING OF OSCILLATOR SYSTEM FOR THE CASE OF THE PLANETARY MIXER WITH TWO VERTICAL AXIS OF 2.50 M^3

3.1. Case 1 – Based Mixer

It is consider the case of the planetary mixer with two vertical axis of capacity 2.50 m^3, shown schematically in figure 1 and constructively in figure 3, having the following technical and technological characteristics [19]:
- standard dimensions: D=3470 mm; h_m= 580 mm; H =1230 mm;
- engines power: 2 x 45 kW;
- central rotor speed: n_{r1}= 15 rot/min;
- blades rotors speed: n_{r2}= 30 rot/min
- number of blades: 3+ 3 pieces;
- the diameter of mixer arm: d = 46 mm;
- axial resistance modulus, I_z =21.96 x 10^4 mm^4
- the blades radiuses (on the left side):

R_1= 830 mm; R_2= 755 mm; R_3= 680 mm;
- the blades radiuses (on the write side):

R_4= 830 mm; R_5= 755 mm; R_6= 680 mm
- the blade surface: S_p= 25 cm x 13 cm = 325 cm^2
- the blade mass calculated with relation (2), considering g_p = 1.8 cm, it results: m_p = 4.6 kg.

The excitation pulsations of the system are:

$$\omega_{r1}=\frac{\pi n_{r1}}{30} \quad (22)$$

from which it results ω_{r1}= 1,57 rad/s.

Figure 3.The planetary mixer of 2.50 m^3 capacity

$$\omega_{r2}=\frac{\pi n_{r1}}{30},$$

from which it results ω_{r2}= 3.14 rad/s.

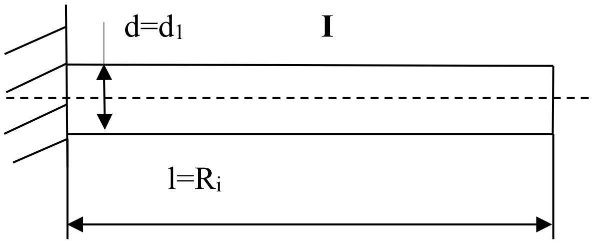

Figure 4. Arm constructive shape in the initial version - case 1

Applying the relations (1) - (21) for the planetary mixer of 2.5 m^3 capacity in the initial version, for determining the vibration movement parameters for the blades situated on the left group (blades no. 1, 2 and 3), we obtain the values from table 1.

Table 1. Parameters values for the arm-blade systems in the initial version- case 1

Blade no.	M_i (kg)	ω_i rad/s)	k_i (N/m)	A_i (m)
1	2246.35	10.39	242606.9	0.23
2	2024.3	12.60	321739.5	0.16
3	1842.1	15.56	446283.8	0.11

3.2. Case 2 - Stiffness variaton of the arm-blade system, by constructive mixer arm modification (I/2)

The arm-blade system is modified by redesigning the arm as in figure 5, in which the arm element of diameter d_2 and length 3 l / 4 has the axial resistance modulus equal to half of the value Iz.

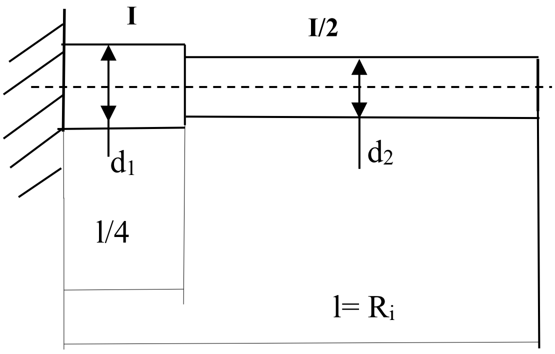

Figure 5. Constructive shape of the arm in modified version - case 2

This change in arm stiffness leads to the recalculation of the new arrow of the arm-blade system (composed of the arrows sum of the two elements of lengths l/4 and 3l/4 and having resistance modules I and I/2), according to the relation:

$$f = f_1 + f_2 = \frac{F(l/4)^3}{EI} + \frac{F(3l/4)^3}{EI/2} = \frac{55Fl^3}{64\,EI} \quad (23)$$

in which I= $I_z = 21.96 \times 10^4$ mm^4

For the expression of the own pulsation it results:

$$\omega = \sqrt{\frac{64EI}{55\,M_i l_i^3}} \quad (24)$$

From the relation for the resistance axial modulus we obtain: d_2=38 mm.

Applying the relations (1)- (23), for the three blades of the planetary mixer left group, we obtain the values figured in table 2.

Table 2. Parameters values for the arm-blade systems in modified version- case 2

Blade no.	M_i (kg)	ω_i rad/s)	k_i (N/m)	A_i (m)
1	2050.22	6.77	93967.5	0.54
2	1865.6	8.17	124795.9	0.37
3	1681	10.14	173104	0.24

3.3. Case 3 - Stiffness variaton of the arm-blade system, by constructive mixer arm modification (I/3)

The arm-blade system is modified by redesigning the arm as in figure 6, in which the arm element of diameter d_2 and length 3l/ 4 has the axial resistance modulus equal to one third of the value I.

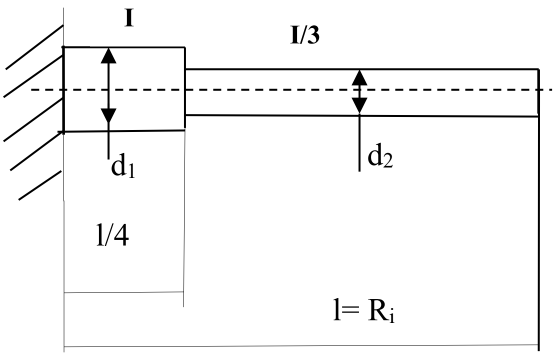

Figure 6. Constructive shape of the arm in modified version – case 3

This change in arm stiffness leads to the recalculation of the new arrow of the arm-blade system (composed of the arrows sum of the two elements of lengths l/4 and 3l/4 and having resistance modules I and I / 3), after the relation:

$$f = f_1 + f_2 = \frac{F(l/4)^3}{EI} + \frac{F(3l/4)^3}{EI/3} = \frac{82Fl^3}{64\,EI} \quad (25)$$

The relation for pulsation calculation becomes:

$$\omega = \sqrt{\frac{64EI}{82\,M_i l_i^3}} \quad (26)$$

From the relation for the resistance axial modulus we obtain: d_2=35 mm.

Applying the relations (1)- (26), we obtain the values figured in table 3.

Table 3. Parameters values for the arm-blade systems in modified version – case 3

Blade no.	M_i (kg)	ω_i rad/s)	k_i (N/m)	A_i (m)
1	1976.6	5.65	63145.6	0.78
2	1798.6	6.82	83704.6	0.53
3	1620.7	8.46	116106.3	0.35

4. THE MOVEMENT AMPLITUDE VARIATION IN RELATION TO THE BLADES PULSATIONS, FOR PLANETARY MIXER OF 2.50 M³

In the figure 7 is shown the movement amplitude variation depending on the arm-blade systems pulsations for planetary mixer, in the initial version - case 1. The graph represents the values of the amplitudes calculated by relation (20), by insertion the blade pulsations, the calculated masses, the elastic constants and the damping factor values. The graph shows the motion damping mode for the blades on the left group, starting from the blade number one the farthest from the own rotor, with a maximum amplitude of 0.236 m and up to the blade number three closest to it, with a maximum amplitude of only 0.105 m. The graph also shows the central rotor excitation pulsation ω_{r1} and the blades own rotor pulsation ω_{r2}) to highlight the blades amplitudes values when passing through this pulsations values. It is observed the amplitude decrease with the blade position close to rotor, at the same time the pulsations increase at values more and more distant from the two excitation pulsations.

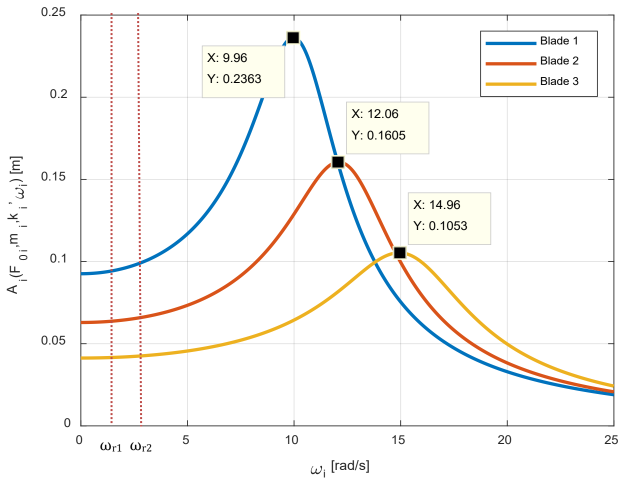

Figure 7. Amplitude variation depending on the arm – blade pulsation in case 1

Figure 8 shows the graphical representation of the motion amplitude variation for case 2, which indicates the improved effect of the arm-blade system elasticity increasing on the motion damping degree, starting from the blade farthest from the own rotor (the first), with a amplitude maximum value of 0.556 m, clearly superior to the previously presented case and up to the blade closest to it (the third), with the maximum amplitude of 0.247 m. There is an obvious amplitudes increase in relation to the previous version, as well as the blades own pulsations decrease in the sense of approaching the two excitation pulsations values.

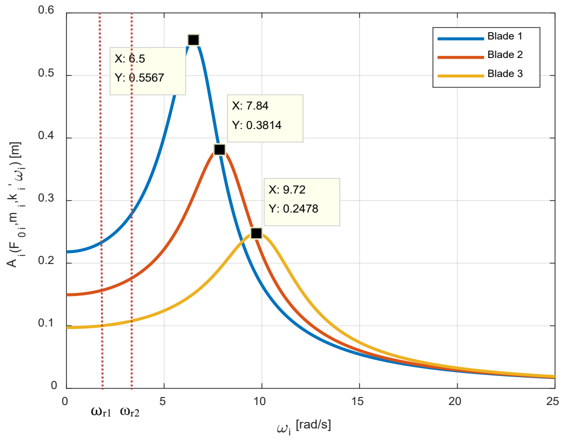

Figure 8. Amplitude variation depending on the arm – blade pulsation in case 2

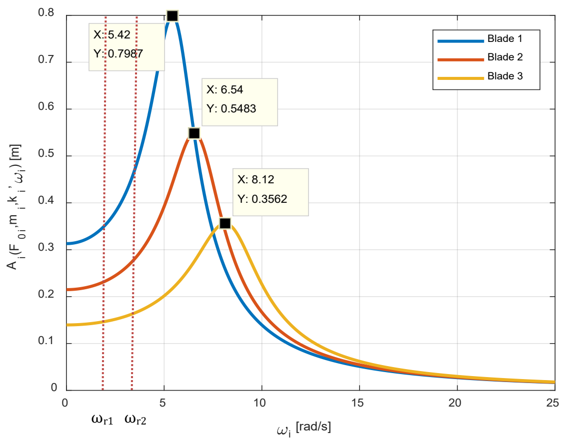

Figure 9. Amplitude variation depending on the arm – blade pulsation in case 3

Figure 9 shows the movement amplitude variation depending on the blades pulsations for case 3, in which the pronounced increase influence of the system elasticity on the damping phenomenon attenuation is observed, starting from the blade farthest from the own rotor (the first), having the maximum amplitude reaching at 0.798 m and up to the blade closest to it (the third), with a maximum amplitude of 0.356 m. The pulsation values are reduced to half of the values obtained in the initial case (the planetary mixer without arm-blade systems constructive modifications), approaching even more much near the rotors pulsations values and the blades amplitudes close to the rotor increase to values comparable to the initial ones, for the blades located away from the rotor.

5. CONCLUSIONS

In accordance with the results presented in tables 1-3 and in the graphs from figures 7-9, the following conclusions can be summarized:

- in case 1, the arm-blade systems vibration movement for the planetary mixer with two vertical axis of 2.50 m^3 is characterized by high blades pulsations in relation to the excitation pulsations, as well as relatively low amplitudes, indicating the motion damping high degree;
- the mixer arm redesign presented in case 2 brings a system elasticity improvement, in the sense that there is an obvious movement amplitudes increase and the blades own pulsations are significantly closer to the rotors pulsations, which can bring a materials homogenization improvement at mixing;
- the system stiffness change presented in case 3 leads to blades pulsations even closer to the excitation pulsations and the amplitude values indicates a very good homogenization, also the arm-blade system resistance module ensures in this conditions sufficient operational reliability, even in the case of high strength concrete mixing;
- the successive mixer arm constructive shape modification, with the effect of the arm-blade system elasticity increasing especially in case 3, considered the best redesigning arm solution, led to the decreasing of the blades movement damping degree, allowing the materials mixing performances increase, with maintaining optimal wear resistance in the event of severe operating conditions;
- the case 3 represents the best solution to redesign the arm-blade system, due to the new arm shape and also the new arm diameter (implicitly the new composed resistance modulus of the arm-blade system), which can assure sufficient wear resistance in operation for kneading mixture with more high density and also the mixing energy consumption is lower in this case.

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