Driving machine shaft angular velocity impact on motion conditional change of granular medium in working reservoir for components compounding and process

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Abstract
The granular operating medium moving in mixing and tumbling working reservoir can be implemented by cascade, waterfall and mixed motion mode of granular medium. Each granular medium motion mode corresponds to certain components process type of different branches of industry or substances mixing. The establishment of relationship between driving machine shaft angular velocity and granular operating medium motion mode is relevant objective for different branches of industry where this equipment is used.
On the basis of 3D modeling and kinematic analysis, some kinematic machine parameters are determined in CAD SolsdWorks, the relationship between driving machine shaft angular velocity and granular operating medium motion mode was established analytically for proportionally modified working reservoir geometrics.
Key words: GRANULAR MEDIUM MOTION MODE, CRITICAL ANGULAR VELOCITY, WORKING RESERVOIR

The components mixing and process machine design, which working reservoir uses complex spatial motion, has been considered; the machine model is represented in Fig. 1.

This machine is used for mixing of granular and liquid substances as well as for components processing of various industry branches, which point is components separating from pouring, burrs removing, grinding, polishing and glossing of their surface.

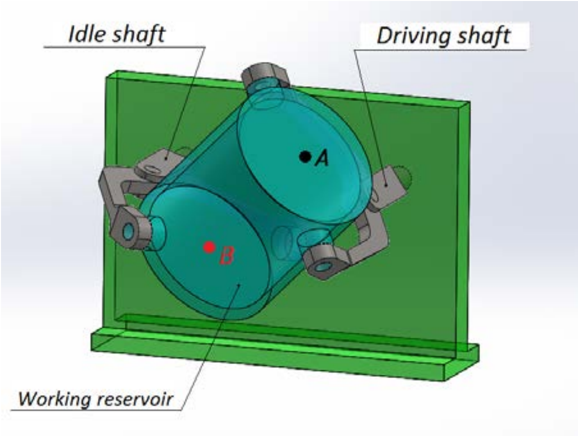

Figure 1. Components compounding and process machine model.

The previous researches [1] established that motion mode change of granular operating medium is directly-proportional to maximum complex accelerations $a^{\max A}$ and $a^{\max B}$ of points A and B respectively; these points align with cylindrical working reservoir bases centers. However, accelerations $a^{\max A}$ and $a^{\max B}$ will have different values [2] for the same driving shaft angular velocity of machines, which have proportionally different working reservoirs geometrics, and also driving machine shaft angular velocity boundary values, which will characterize the motion mode change of granular medium for each proportionally changed machine design, will differ from each other. Let us establish the maximum complex accelerations $a^{\max A}$ and $a^{\max B}$ values dependence from proportionally different working reservoirs geometrics for various driving shaft angular velocities. For this purpose, let us conduct the kinematic investigation of 3 components compounding and process machine designs [3] with proportionally different working reservoirs geometrics by CAD SolsdWorks.

Let us designate machine design, which has already been investigated [1], as “basic”. It has the following parameters: working reservoir (cylindrical drum) length - 140 mm, working reservoir diameter – 124 mm, working reservoir volume – 1.6 dm^3.

Let us take corresponding scaling coefficients 2 and 3 for two other design variants. In so doing, investigated machine models will have the following geometrics.

When scaling coefficient ***m=2***, working reservoir (cylindrical drum) length - 280 mm, working reservoir diameter – 248 mm, working reservoir volume – 13.5 dm^3.

When scaling coefficient ***m=3***, working reservoir (cylindrical drum) length - 420 mm, working reservoir diameter – 372 mm, working reservoir volume – 45 dm^3.

The maximum values of complex accelerations $a^{\max A}$ and $a^{\max B}$ for 3 components machine designs with various driving machine shaft angular velocities are shown in Table 1.

Table 1

	“Basic” machine design, ***m=1***		machine design with scaling coefficient ***m=2***		machine design with scaling coefficient ***m=3***	
ω,[rad/s]	$a_1^{\max A}$,[m/s^2]	$a_1^{\max B}$,[m/s^2]	$a_2^{\max A}$,[m/s^2]	$a_2^{\max B}$,[m/s^2]	$a_3^{\max A}$,[m/s^2]	$a_3^{\max B}$,[m/s^2]
0,525	0,09	0,27	0,18	0,54	0,27	0,81
1,05	0,36	1,1	0,72	2,1	1,1	3,3
2,1	1,45	4,4	2,9	9	4,4	13,2
3,15	3,3	10	6,6	20	9,5	30
4,2	5,8	17,6	11,6	35,2	12,6	52,8
5,25	9	27,5	18	55	27	82,5
6,3	13	39,6	26,2	79,2	39	118,8

7,35	17,6	53,9	35,3	107,8	52,8	161

Let us depict the values from Table 1 in the form of characteristic curve, which is presented in Fig. 2.

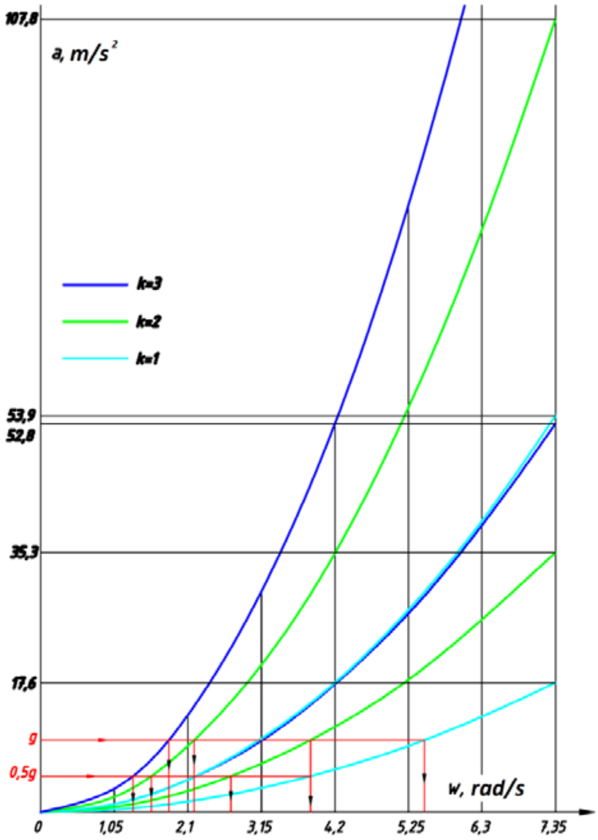

Figure 2. The 3 machine designs accelerations $a^{\max A}$ and $a^{\max B}$ -vs-driving shaft angular velocity **ω** curve

Having analyzed the characteristic curve shown in Fig. 2, it has been established that accelerations $a^{\max A}$ and $a^{\max B}$ of 3 machine designs differ when the same driving shaft angular velocity ***ω***. Moreover, the complex accelerations $a^{\max A}$ and $a^{\max B}$ values, which appertain to points A and B and align with cylindrical working reservoir bases centers, differ from each other when the same driving shaft angular velocity. And also, the granular medium irregular motion phenomenon will be observed when being in different parts of working reservoir [4]. When proportionally increased working reservoir geometrics, the accelerations values will be increasing and vice versa. At that, this accelerations change will be also directly-proportional depending on the scaling coefficient ***m***, therefore:

$$a_m^{\max A(\max B)} = a_1^{\max A(\max B)} \cdot m \qquad (1)$$

where $a_1^{\max A(\max B)}$ - "basic design" working reservoir corresponding point acceleration, [m/s^2];

m - scaling coefficient (***m=1;2;3***);

$a_m^{\max A(\max B)}$ - substatic working reservoir corresponding point acceleration, [m/s^2].

It has been established that accelerations $a^{\max A}$ and $a^{\max B}$ growth from driving shaft angular velocity ***ω*** will go on in accordance with quadratic function of the form

$$y = kx^2 \qquad (2)$$

When coordinate axis corresponding values and the scaling coefficient **m**, the formula (2) will be of the form

$$a_m^{\max A(\max B)} = mk^{\max A(\max B)} \left(\omega_{A(B)} u\right)^2 \qquad (3)$$

where $\omega_{A(B)}$ - driving machine shaft angular velocity;

u - characteristic curve scaling coefficient, which characterizes the ratio complex acceleration unit [m/s^2] to angular velocity unit [rad/s], in this particular case $u = 9{,}52\left[\frac{m/s^2}{rad/s}\right]$;

k – empirically established nondimensional coefficient, which characterizes the curve symmetrical distance from ordinate axis when the same corresponding abscissa axis value for "basic machine design". Using the formula (2), it was determined that: ***k^A≈0,0036; k^B≈0,011.***

The equation (3) for "basic design" complex accelerations $a^{\max A}$ and $a^{\max B}$ determination considering coefficients ***k^A*** and ***k^B*** will be of the form

$$a_1^{\max A} = mk^A(\omega_A u)^2 = 0{,}0036(\omega_A u)^2 \qquad (4)$$

$$a_1^{\max B} = mk^B(\omega_B u)^2 = 0{,}011(\omega_B u)^2 \qquad (5)$$

By the same principle, the equations for complex accelerations $a^{\max A}$ and $a^{\max B}$ determination for machines design with scaling coefficient 2 or 3 can be written.

From equations (4, 5), it was determined that

$$\frac{k^B}{k^A} \approx 3{,}05 \qquad (6)$$

The equation (3) considering formula (6) will be of the form of $a^{\max A}$ and $a^{\max B}$ definitions:

$$a_m^{\max B} = 3{,}05mk^A(\omega_B u)^2 \qquad (7)$$

$$a_m^{\max A} = \frac{mk^B(\omega_A u)^2}{3{,}05} \qquad (8)$$

Let us evaluate driving machine shaft angular velocity values from formulas (7) and (8):

$$\omega_B = \sqrt{\frac{a^B}{3{,}05mk^A u^2}} \qquad (9)$$

$$\omega_A = \sqrt{\frac{3{,}05a^A}{mk^B u^2}} \qquad (10)$$

It is known [5] that motion mode will not considered as cascade, it will be mixed cascade-waterfall if the particles quantity equal to 50% of granular medium combined mass separates from granular medium total mass. The motion mode will be waterfall if the entire granular medium≈100% separates from reservoir wall. Analyzing the forces affecting the granular massif, it is arguable that granular medium motion mode will be waterfall if complex accelerations $a^{\max A}$ and $a^{\max B}$ maximum values are higher than g=9.81 m/s^2 (total inertial force of the entire granular massif will be higher than its total attractive force). Moreover, the granular medium motion mode will cease to be cascade if complex accelerations $a^{\max A}$ and $a^{\max B}$ maximum values are higher than 0.5g m/s^2.

Let us provide the general form to equations (9) and (10), so it will be possible to establish driving machine shaft angular velocity boundary values, which will affect the granular medium motion mode changes in working reservoir:

$$\omega_B^{BOUND} = \sqrt{i\frac{g}{3{,}05mk^A u^2}}, [rad/s] \qquad (11)$$

$$\omega_A^{BOUND} = \sqrt{i\frac{3{,}05g}{mk^B u^2}}, [rad/s] \qquad (12)$$

where ***g*** - gravitational acceleration, [m/s^2];
i **–** total volume granular medium part, which will separate from granular massif.

When ***i=1/2*** (the half volume will separate from granular massif surface), the formula will characterize the driving machine shaft angular velocity boundary coefficient that will be transition from cascade to mixed granular medium motion mode.

When ***i=1*** (the entire granular medium massif can separate from working reservoir surface), the formula will characterize the driving machine shaft angular velocity boundary coefficient that will be transition from mixed to waterfall granular medium motion mode.

Due to granular medium motion inhomogeneity inside the working reservoir, it is possible to establish the necessary driving shaft angular velocity for granular medium motion mode change determination in that working reservoir part, which is closer to driving shaft, by the equation (12), and for granular medium motion mode change determination in that working reservoir part, which is closer to idle shaft, by the equation (11).

Let us establish the general boundary values of driving machine shaft angular velocity by analytic method using the equations (11) and (12) graphic approach based on the use of dependence diagram, shown in Fig. 2. These values will conform to the granular operating medium motion modes change for corresponding scale machine options and they are shown in Table 2.

Table 2

ω[rad/s] m=1	ω[rad/s] m=2	ω[rad/s] m=3	Granular medium motion mode
0-2,22 2,22-3,81 3,81-5,4	0-1,56 1,56-2,3 2,3-3,87	0-1,28 1,28-2,22 2,22-3,16	Cascade Mixed (cascade-waterfall) Mixed (waterfall- cascade)
5,4<	3,87<	3,16<	Waterfall

Conclusion

1. It has been established that granular operating medium motion modes change in working reservoir depends on overall machine parameters. It has been proved that in machine with proportionally modified working reservoir geometrics, the transition from cascade to mixed and waterfall motion mode will carry more intensive than when machine "basic design", and vice versa.

2. The equation for determination of driving machine shaft boundary angular velocity, which will conform to granular medium necessary motion mode implementation when its motion in corresponding working reservoir part, has been obtained.

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