Determination of technological and power parameters of mixer-homogenizer

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Abstract
The calculation methods on determination of productivity and power parameters of mixer-homogenizer of vertical action with rotor blades rotating in parallel and uniformly towards each other are presented in the article.
Key words: MIXER, PRODUCTIVITY, POWER, DESIGN FACTORS

The mixer (Figure 1) for simultaneous carrying out of disintegration and homogenization of scale-peat compound with the use of effect of natural gravitation that makes it possible to reduce the electricity consumption on material transportation in the mixer chamber from loading to unloading was developed by employees of Kryvyi Rih Iron and Steel Institute SHEI "KRNU" together with SE " Kryvyi Rih Higher Metallurgical School".

Basic elements of the mixer are the following: portal of 1 welded structure, where the frame 2 with the hopper 3, and also framework 4, in which the cylinder shells 5 are set with horizontal turning angle of 90 ° relative to each other, are arranged. Each cylinder shell consists of four shafts (6, 7, 8, 9), which are parallel with each other. The turner 10 with gap L' is fixed in chessboard order on these shafts. The rotation is transmitted to the leading shaft (6) from the motor reducer 11 through the chain gear 12. Rotation is transmitted to the shafts 7, 8, 9 from a shaft 6 through tooth gearing 13; therefore, the shafts rotate to the opposite directions relative to each other. The fixed edges 14 are arranged relative to blades perpendicular to the shafts in chessboard order on the sidewalls. The constructive diagram of turner fixing on a shaft with designation of the connecting dimensions is shown in Figure 2 [1, 2].

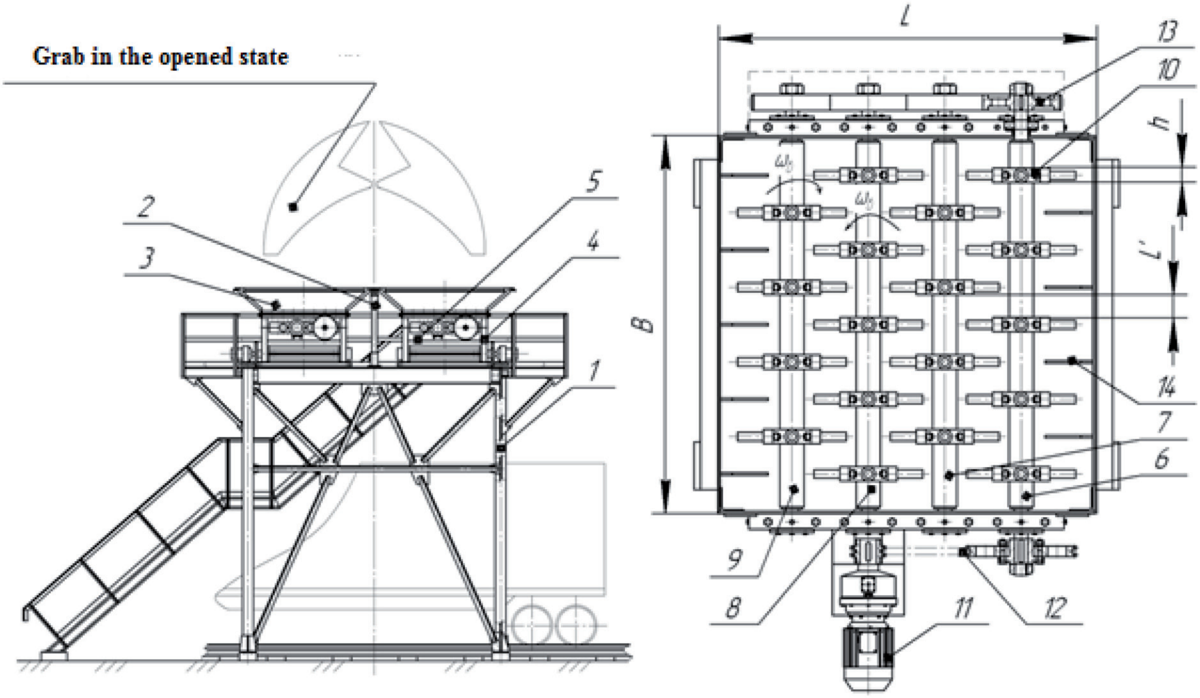

Figure 1. Constructive diagram of the mixer-homogenizer

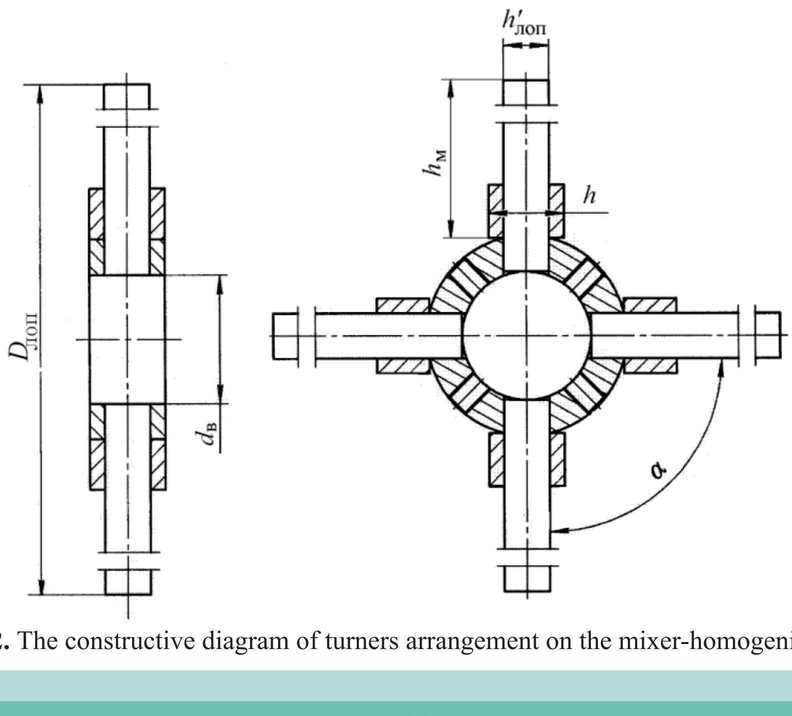

Figure 2. The constructive diagram of turners arrangement on the mixer-homogenizer shaft

As the mixer-homogenizer must provide high productivity in case of energy-efficient operation, when its developing, the determination of regularities, which reveal the influence of technological and kinematic data of its working body on the main technological and power indices of mixing process, is primary. Thus, the purpose of the investigations was development of an engineering technique of determination of the main indices of mixer operation, such as productivity and power of the drive.

From the design features of the mixer homogenizer shown in Figures 1 and 2, it is obvious that on the one hand, first cylinder shell functions as lock, on the another hand, it functions as measuring device, which can be considered as a drum feeder (where shafts are arranged) and sluic metering unit (where blades are arranged). In this case, productivity of the considered mixer can be determined as follows:

$$P = P' + P'' \text{ m}^3/\text{h}$$

where P′ - productivity determined by the drum metering unit, m^3/h; P″ - productivity determined by the sluic metering unit, m^3/h.

According to [3] and constructive diagram of cylinder shell, productivities of drum and sluic metering unit can be determined by the following dependences:

$$P' = 1800 \cdot h_m \cdot (B - h \cdot n_{tur}) \cdot d_{sh} \cdot n_{sh} \cdot \omega_{sh} \cdot K_p \text{ m}^3/\text{h}, \quad (2)$$

where h_m – height of material layer, which is carried away by shaft, m (see Figure 2); B – width of turners number; d_{sh} – shaft diameter, m; n_{sh} – number of shafts; ω_{sh} – angular speed of a shaft, s^{-1}; K_p – productivity coefficient depending on properties of the process material ($K_p = 0,7 \ldots 0,8$) [3].

$$P'' = 1,25 \cdot D_{bl}^2 \cdot \alpha \cdot h'_{bl} \cdot n_{tur} \cdot \omega_{sh} \cdot K_p \cdot n_{bl} \text{ m}^3/\text{h}, \quad (3)$$

where D_{bl} – outer diameter of blade (see Figure 2), m; α – angle forming a bay, degree; h'_{bl} – width of blade, m; n_{bl} – blade number in the turner.

Substituting expressions (2) and (3) into a formula (1), we obtain:

$$P = \omega_{sh} K_p \left(1800 \cdot h_m \cdot (B - h \cdot n_{tur}) \cdot d_{sh} \cdot n_{sh} + 1,25 \cdot D_{bl}^2 \cdot \alpha \cdot h'_{bl} \cdot n_{tur} \cdot n_{bl}\right) \text{ m}^3/\text{h}. \quad (4)$$

In the obtained formula (4), angular speed of a shaft should not exceed critical value, in case of which the particles are separated away from a surface in the top point of blade:

$$\omega_{sh} < \omega_{cr} = \sqrt{2g/D_{bl}} . \quad (5)$$

The necessary power of the drive of shell according to [4] can be determined by the following formula:

$$N_{dr} = \left(K'_p \cdot (M_m + M_{csh}) \cdot \omega_{sh}\right) \Big/ \left(\eta_1 \cdot \eta_2 \cdot \eta_3^{n_{lev}}\right) \text{ kW}, \quad (6)$$

where K'_p – assurance coefficient of installation power, proceeding from [3] accepted as K'_p = 1,2; M_m – sum moment from an actual load of material on shaft and blades, Kn·m; M_{csh} – moment of friction in the shaft cylinder shell, kN×m; η_1 – efficiency coefficient of reducing gear; η_2 – efficiency coefficient of chain gear; $\eta_3^{n_{lev}}$ – efficiency coefficient of tooth gearing in one level taking into account the losses in bearings; n_{lev} – number of levels in the tooth gearings (for the considered case n_{lev} =3).

According to recommendations [5], efficiency of separate nodes may be accept as follows: $\eta_1 = 0,98$; $\eta_2 = 0,97$; $\eta_3 = 0,95$.

From all specified parameters in a formula (6), sum moment from an actual load of material on shaft and blades, and also friction forces in the center shaft.

For determination of actual load of material on shaft and blades, the calculation diagram shown in Figure 3 was accepted.

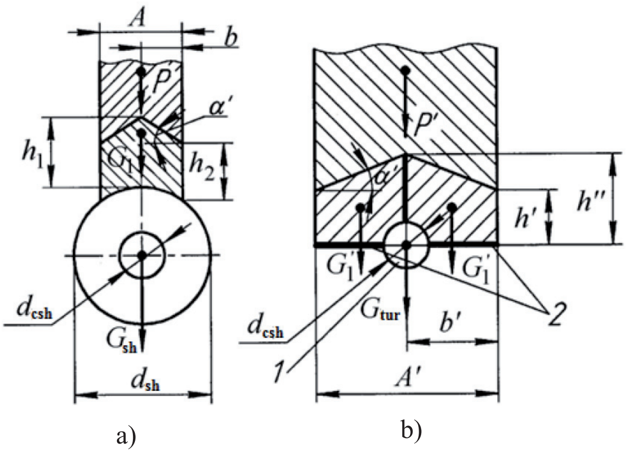

Figure 3. The diagram of applied forces:
a) - to the mixer shaft; b) - to the mixer blades; 1 - shaft; 2 - blade of mixer

In the diagram P and P' – material pole pressure upon a shaft and blades of mixer respectively, kPa; A and A' – material column width, m; G_1 and G'_1 – gravity of the prism of material lying on a shaft and blades respectively, kN; G_{sh} and G_{tur} – gravity of shaft and turner, kN; α' – material repose angle, degree.

Sum moment from an actual load of material on shaft and blades is equal to

$$M_m = \sum P_{sh} \cdot f \cdot \frac{d_{sh}}{2} + \sum P_{bl} \cdot f \cdot \frac{D_{bl}}{2} \text{ kN×m}, \quad (7)$$

where f – coefficient of material friction on shaft and blades. The moment of friction forces in center shafts will be determined as follows

$$M_{csh} = \left(\sum P_{sh} + \sum P_{bl} + G_{sh} \cdot n_{sh} + G_{tur} \cdot n_{tur}\right) \cdot \mu' \cdot \left(d_{csh}/2\right) \text{ kN×m,} \quad (8)$$

where μ' – friction coefficient in bearings; d_{csh} – diameter of central shaft of mixer, m.

Substituting (7), (8) into (6), we obtain design value of power for the first cylinder shell

$$N^{I-I} = \frac{K'_p \cdot \left(\sum P_{sh} \cdot f \cdot \frac{d_{sh}}{2} + \sum P_{bl} \cdot f \cdot \frac{D_{bl}}{2} + \left(\sum P_{sh} + \sum P_{bl} + G_{sh} \cdot n_{sh} + G_{tur} \cdot n_{tur}\right) \cdot \mu' \cdot \left(d_{csh}/2\right)\right) \cdot \omega_{sh}}{\eta_1 \cdot \eta_2 \cdot \eta_3^{n_{lev}}} \text{ kW.} \quad (9)$$

According to the diagram of applied forces and construction diagram of cylinder shell, the sum forces applied to the shafts ($\sum P_{sh}$) and blades ($\sum P_{bl}$) will be equal.

$$\sum P_{sh} = P \cdot A\left(B \cdot n_{sh} - h \cdot n_{tur}\right) + G_1 = P \cdot A\left(B \cdot n_{sh} - h \cdot n_{tur}\right) + \left(h_1 + h_2\right) \cdot b \cdot \left(B \cdot n_{sh} - h \cdot n_{tur}\right) \cdot \gamma \cdot g \text{ kN;} \quad (10)$$

$$\sum P_{bl} = P' \cdot A' \cdot h \cdot n_{tur} + 2G'_1 = P' \cdot A' \cdot h \cdot n_{tur} + \left(h' + h''\right) \cdot b' \cdot h \cdot n_{tur} \cdot \gamma \cdot g \text{ kN,} \quad (11)$$

where h_1 and b are less than 150 mm for shaft diameters, they may be accepted as: $h_1 = d_{sh}/2$, m; $b = d_{sh}/3$, m; γ – pour density of material kg/m^3; g – acceleration of gravity m/s^2.

Pressure upon one shaft P and row of blades P' arranged on the mixer shaft according to recommendations [6] can be determined as follows:

$$P = \left[\gamma \cdot g \cdot \left(L \cdot B/2\left(L + B\right)\right)\right] \Big/ \left[\left(\left(1 - \sin\alpha_{in.f}\right)/\left(1 + \sin\alpha_{in.f}\right)\right) \cdot f_{in} \cdot n_{sh}\right] \text{ kPa;} \quad (12)$$

$$P' = \left[\gamma \cdot g \cdot \left(L \cdot B/2\left(L + B\right)\right)\right] \Big/ \left[\left(\left(1 - \sin\alpha_{in.f}\right)/\left(1 + \sin\alpha_{in.f}\right)\right) \cdot f_{in} \cdot n_{tur}\right] \text{ kPa,} \quad (13)$$

where $\alpha_{in.f} = arctg\ f_{in}$ – angle of inner friction of pour material, degree; f_{in} – coefficient of inner friction of pour material.

For the second cylinder shell, power consumption is expended for mixing (transportation) of material, and also for friction in shaft supports and can be determined as

$$N^{II-II} = \left(A_{tr} + M_{tr}\right) \cdot \omega_в \Big/ \left(\eta_1 \cdot \eta_2 \cdot \eta_3^{n_{lev}}\right) \text{ kW,} \quad (14)$$

where A_{tr} – work necessary for mixing (transportation) of material, kJ; M_{tr} – moment of friction forces in shaft bearings, kN×m.

The work on mixing (transportation) was determined by energy costs condition against friction taking place in case of interaction of blades with material. The value of friction depends on radial pressure of blade on piece of the mixed material; the friction force provides the necessary centrifugal force for displacement of the weight-average piece with mass m_0. Researches of material particle movement in the chamber of working body of the portal-mixer homogenizer have shown that centrifugal force considerably exceeds the force of radial pressure in case of considered technological process; thus, the latter can be neglected for further calculations. In this case, the work on mixing (transportation) is determined as follows:

$$A_{tr} = m_0 \cdot \omega_{sh}^2 \cdot n_{tur} \cdot \left(D_{bl} - d_{sh}\right) \cdot \left(D_{bl}/2 - \sqrt[3]{m_0}/2 \cdot \sqrt[3]{\gamma}\right) \text{ kJ,} \quad (15)$$

where m_0 – mass of one piece of material, kg.

Supposing that each blade during one turn of a shaft mixes the productivity-average amount of material, the mass of a piece with some admission on margin side can be determined as follows:

$$m_0 = \left(\Pi \cdot \gamma\right) / \left(3600 \cdot \omega_{sh} \cdot n_{tur}\right) \text{ kg.} \quad (16)$$

Let us use the following formula for determination of moment of friction forces in shaft bearings:

$$M_{tr} = \left(G_{sh} \cdot n_{sh} + G_{tur} \cdot n_{tur}\right) \cdot \mu' \cdot \left(d_{csh}/2\right) \text{ N·m.} \quad (17)$$

After substitution of value of transportation work of material from formula (15) and the moment of friction forces in bearings from (17) into (14), it is possible to calculate the power consumption on the subsequent cylinder shells of the mixer:

$$N^{II-II} = \frac{\left(m_0 \cdot \omega_{sh}^2 \cdot n_{tur} \cdot \left(D_{bl} - d_{sh}\right) \cdot \left(\frac{D_{bl}}{2} - \frac{\sqrt[3]{m_0}}{2 \cdot \sqrt[3]{\gamma}}\right) + \left(G_{sh} \cdot n_{sh} + G_{tur} \cdot n_{tur}\right) \cdot \mu' \cdot \left(d_{csh}/2\right)\right) \cdot \omega_{sh}}{\eta_1 \cdot \eta_2 \cdot \eta_3^{n_{lev}}} \text{ kW.} \quad (14)$$

Conclusions

The engineering method for mixer-homogenizer of vertical action with rotor blades rotating in parallel and uniformly towards each other was developed. The method determines its productivity and drive power considering the design features and linkage parameters, which make it possible to carry out the optimization and selection of basic geometrical sizes of working body of the mixer at a design stage for different technological tasks and loadings.

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