Research of the speed flows of the charge on the surface of the rolls of the press-rollers extruder

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Abstract. In the production of building materials, the processes of grinding and extruding the mixture with roll-type units are accompanied by uneven wear of the working bodies as a result of uneven distribution of material across the width of the rolls, which subsequently affects the quality of the finished product. In addition to the above, feeding the charge to the edge of the press plane rolls in the press-roller extruder leads to a bolted joints thread extraction of the fixed side surface. In this article, based on the results of analytical studies of the movement of the charge process to the forming zone, a possible solution of the emerging problems with press-roll extruder working bodies of uneven wear was proposed and argued.

1. Introduction

One of the promising areas for the development of high-tech technologies is the development and creation of multifunctional technological complexes that provide the finished product in a molded form (in the form of pellets or briquettes). It is possible to obtain compressed granules using press-roller extruders (PRE) of various structural and technological designs [1,2].

The main areas of structural and technological improvement of PRE [3-5] include:
- ensuring uniform feeding of the pressed material and its effective pre-compaction [6];
- the implementation of material thermal heating and the introduction of various plasticizers into it [7];
- ensuring reliable capture of the material by a pressing body (rollers) [8,9], pressure hold and using vibrations;
- improving the operational reliability of the unit, as well as the service life of the working bodies, etc.

Experience in the operation of most roller-type units (press-roller shredders, roller presses, chaser mill, roller mills, etc.) indicates the uneven flow of the processed material across the width of their working bodies (rolls) [10,11]. We observed a similar phenomenon during pressing in PRE. The purpose of this work is the observation of charge motion conditions.

2. Results

In this regard, it is necessary to study the conditions of motion of the charge in the working pair “press plane – pressing roll” (figure 1) of the press roll extruder.

Figure 1 presents the interaction scheme of PRE working bodies.
Let us assume that there are the conditions of movement of the charge across the width of the PRE forming pair: press plane - pressing roll (figure 2).

We use a system of differential equations in cylindrical coordinates describing the motion of a viscous non-compressible fluid to study the process of charge movement.

\[
\begin{align*}
\frac{\partial V_R}{\partial t} + V_R \frac{\partial V_R}{\partial R} + \frac{\partial V_R}{\partial \varphi} \frac{\partial V_R}{\partial \varphi} + V_R \frac{\partial V_R}{\partial z} &= F_R - \frac{1}{\rho} \frac{\partial p}{\partial R} + \varphi \left( \Delta V_R - \frac{V_R}{R} + \frac{2}{R^2} \frac{\partial V_R}{\partial \varphi} \right) \\
\frac{\partial V_\varphi}{\partial t} + V_R \frac{\partial V_\varphi}{\partial R} + V_\varphi \frac{\partial V_\varphi}{\partial \varphi} + V_R V_\varphi &= F_\varphi - \frac{1}{\rho} \frac{\partial p}{\partial \varphi} + \frac{1}{R} \left( \Delta V_\varphi - \frac{V_\varphi}{R} + \frac{2}{R^2} \frac{\partial V_R}{\partial \varphi} \right) \\
\frac{\partial V_Z}{\partial t} + V_R \frac{\partial V_Z}{\partial R} + V_\varphi \frac{\partial V_Z}{\partial \varphi} + V_R V_Z &= F_Z - \frac{1}{\rho} \frac{\partial p}{\partial \varphi} + \frac{1}{R^2} \frac{\partial V_R}{\partial \varphi} \frac{\partial V_\varphi}{\partial \varphi} + V_\varphi \frac{\partial V_R}{\partial \varphi} \frac{\partial V_\varphi}{\partial \varphi} 
\end{align*}
\]

(1)

where \( P \) – charge pressure; \( R \) – roll radius; \( \varphi \) – rotation angle (reduction) of the charge; \( F_R, F_Z \) – mass forces along radius \( R \) and \( z \) axis, accordingly; \( \rho \) – charge density; \( V_R, V_\varphi, V_Z \) – the velocity of the charge along the roll radius, in the direction of rotation of the roll and the \( z \) axis, accordingly; \( V_t \) – charge speed over time \( t \); \( t \) – compression time.

At the same time the condition of non-compressibility:
\[
\frac{\partial V_R}{\partial R} + \frac{V_R}{R} + \frac{1}{R} \frac{\partial V_\phi}{\partial \phi} + \frac{\partial V_Z}{\partial z} = 0.
\]

(2)

Laplace operator:

\[
\Delta = \frac{\partial^2}{\partial R^2} + \frac{1}{R} \frac{\partial}{\partial R} + \frac{1}{R^2} \frac{\partial^2}{\partial \phi^2} + \frac{\partial^2}{\partial z^2}.
\]

(3)

Assuming that in the zones of non-compressibility of the charge AB and CD (\(\rho=\text{const}\)), the process of material movement is steady, mass forces are negligible, \(F=0\), i.e.:

\[
\frac{\partial V}{\partial t} = 0, \quad \frac{\partial V_\phi}{\partial \phi} = 0.
\]

When considering the second equation of system (5):

\[
\frac{1}{R} \frac{\partial P}{\partial \phi} = \eta \left( \frac{\partial^2 V_\phi}{\partial z^2} - \frac{V_\phi}{R} \right).
\]

(4)

When considering the second equation of system (5):

\[
\frac{1}{R} \frac{\partial P}{\partial \phi} = \eta \left( \frac{\partial^2 V_\phi}{\partial z^2} - \frac{V_\phi}{R} \right) \quad \text{or} \quad \frac{1}{R} \frac{\partial P}{\partial \phi} = \eta \left( \frac{\partial^2 V_\phi}{\partial z^2} - \frac{V_\phi}{R^2} \right).
\]

(5)

We see that the right side of the last equation is a function of the \(z\) coordinate, and the left is a \(\phi\) function. This equation may be subject to \(\frac{\partial P}{\partial \phi} = C\).

After further transformations, expression (6) takes the form:

\[
V_\phi = V_2 - V_1 \left( e^{\frac{Z}{\eta R}} - e^{-\frac{Z}{\eta R}} \right).
\]

(7)

The analysis of the geometric dependence \(V_\phi(f(z))\) (figure 2), built according to the formula (7), shows that when the charge moves to the compression zone, the speed of the material flow varies along the width of the rolls according to a parabolic law. The maximum values \(V_\phi\) are observed in the middle of the rolls (p. S and S', figure 2), the minimum values are on their edges (p. N, N' and K, K '), which is due to the near-wall effect of the side surfaces of the press plane.

To study the power parameters arising from the movement of the charge in the forming zone, we analyze the resulting equation (4).

The analysis shows that under stable forming conditions (uniform feeding of the charge with constant physical-mechanical characteristics: humidity, density, etc., the constant frequency of rotation of the press plane, etc.), a constant force \(P\) appears along the \(z\) axis.

\[
\begin{align*}
\frac{\partial P}{\partial \phi} &= C, \\
\frac{\partial P}{\partial z} &= 0, \\
R &= \frac{1}{\rho} \frac{\partial P}{\partial \phi}.
\end{align*}
\]

(8)

After integrating expression (8), we have:

\[
\begin{align*}
P &= C_\phi + C_3' \\
P &= \rho V_\phi^2 \ln R + C_3'.
\end{align*}
\]

(9)
This system of equations shows that the pressure of the charge is determined by the value of the angle $\phi$ of compression and the radius $R$ of the rolls, i.e. $P=f(\phi, R)$.

In equation (9), the implicit dependence $P$ on $R$ is determined by a constant $C_3$. The implicit dependence $P$ on $\phi$ of the second equation is determined by a constant $C_3'$. Both equations contain an arbitrary constant $C_3$.

Given the above conditions, expression (9) can be represented as:

$$P=C\phi+\rho V_\phi^2 \ln R + C_3,$$  \hspace{1cm} (10)

where

$$C=\omega_1+\theta B R \left(1+\theta^2 R^2\right).$$

The total pressure that occurs when the charge moves to the forming zone is the sum of the pressure determined by the roll angle parameter $\phi$, the speed parameter $V_\phi$ and the magnitude of the charge friction force $F_{fr}$ on the rotating press plane surface, which depends, in turn, on the centrifugal force $F_c$ in a rotating plane.

Expression (10) taking into account the values of constants $C$ and $C_3$ can be represented as:

$$P=\omega n \frac{B}{1+e^B R} \phi+\rho V_\phi^2 \ln R + \rho V_{pp} f + \frac{\rho V_{pp} f}{R_{pp}} f.$$  \hspace{1cm} (11)

The first component of equation (11) is the charge movement resistance to the forming zone $P_{res}$ determined by the angular velocity of the charge $\omega$, its viscosity $\eta$ and angle of rotation of the charge $\phi$ (in rad).

In addition, the process of movement of the charge is also influenced by the width of the press plane (width of the roll – $B$) and the radius of rotation of the charge, determined by the radius of the roll $R$.

In this case, as can be seen from the first component, the greater the width of the roll $B$, the smaller the resistance value of the movement of the charge to the forming zone due to the decrease in the wall effect.

So with a 2-time increase in the width of the roll with $B = 150$ mm to $B = 300$ mm, i.e., $P_{res}$ decreases 3.7 times. Similarly, when reducing the roll radius with $R = 200$ mm to $R = 100$ mm, i.e. 2 times, $P_{res}$ reduces 3.7 times.

Analytical dependence (7) has not only theoretical value, but also practical. So, when feeding the forming charge with a screw into the zone of location of points N and N’ (to the edge of the rolls), the nature of the velocity $V_{\phi}$ distribution across the width of the rolls $B$ is parabolic, but the extremum of the parabola is shifted to the feeding point.

$$V_{f}=f(z), \text{ p. N and } V_{o} = f(z), \text{ p. N’}, \text{ (figure 2).}$$

3. Conclusion

As practice has shown, the distribution of the charge across the width of the rolls at the time of loading is important. When the charge moves to the compression zone, the speed of the material flow along the width of the rolls changes according to a parabolic law. The uneven loading of the charge leads to the bolted joints thread extraction of the press plane fixed side surface. This phenomenon is due to the occurrence of significant lateral thrust. A constant force $P$ arises under stable molding conditions along the $z$-axis. When the charge is loaded with a screw into the central part of the rolls, no concentration of axial forces is observed.

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