New grinder for rye grain and plastics granulate

Introduction

The main point of the multiple cutting mill for particles materials (especially rye grain and plastics particles) is that the device consists of a set of working discs mounted coaxially on a shaft, and the discs have holes of grinding edges arranged on diameters which increase from the inlet to outlet of the material from the comminution area, and the velocity between adjacent discs is a comminution velocity (Fig. 1) [Kamyk, 2008; Chun et al., 2001].

The multiple disc cutting mills belong to that group of devices in which the process is performed as a linear speed of the grinding edge of appr. 1 m/s, and comminuted material still remains within the cutting area [Flizikowski, 2002, Flizikowski, 2011].

The purpose of the work is answer the question: are permanent contact shields, continuous contact of material with the grinding elements and its lower linear velocity – the basic requirements for high effectiveness of the grinding process?

It was assumed that grain particles would be comminuted on the basis of technological quasi-shearing. The state of load and the grain strain of Fig. 2. The interpretation of milling field (A,S) grains may occur on one or two edges formed by holes made in the discs which are in a state of relative motion.

Modelling of the field, forces and milling work

On the basis of many – sided studies one can state that the way of calculation of the milling field – in the process of construction support – is precisely dependent on operational possibilities of a computer [Flizikowski and Bieliński, 2013; Flizikowski, 2006].

The calculation of the milling section \( F_R \) between two holes which have centre co-ordinates \( C_1 (a_1, b_1), C_2 (a_2, b_2) \) means stating the distance between the centres of the holes; assuming that the field \( F_R \) is the sum of two equal circle segments stated by the chord \( B_1B_2 \).

The circle segment area (Fig. 2) is calculated from the formula:

\[
\frac{1}{2} F_R = \frac{1}{2} (\alpha - \sin \alpha) R^2
\]  

where: \( \alpha \) – is the centre angle \(< B_1, C_1, B_2 = < B_2, C_2 B_1 \).

On the geometrical dependences we can obtain the following formula:

\[
F_R = \left(2 \arctg \left[1 - \frac{W}{2R}\right]\right) - \frac{W}{4R} \left[1 - \left(\frac{W}{2R}\right)^2\right] R^2
\]  

(2)

The simulation and calculations of milling field and milling forces were operated as an algorithm written in Turbo-Pascal (Fig. 3).

The energy effectiveness is defined as [Macko, 2000]:

\[
E_R = \frac{L_{\text{out}} - L_{\text{in}}}{L_{\text{out}} + L_{\text{in}}} \cdot 2
\]  

(3)

where: \( L_{\text{out}}, L_{\text{in}} \) are the successive instantaneous increments of the work of quasi-cutting, [Nm].

The mathematical descriptions of the variables given in equations (1) – (3) are obtained from experiments or from data contained in processing tables [Sadkiewicz et al., 2004].

The following characteristics of motors and grinders transmissions are determined in operational trials:

- the kinematic transmission ratio:

\[
i_k = \frac{\omega_2}{\omega_1}
\]  

(4)

- the dynamic transmission ratio:

\[
i_d = \frac{M_2}{M_1}
\]  

(5)

- power at transmission input, equal to the power at the output of the motor:

\[
N_i = N_k = \omega_2 N_2
\]  

(6)

- power at transmission output, equal to the grinding power:

\[
N_s = N_k = \omega_2 N_2
\]  

(7)

- efficiency of the motor:

\[
\eta_i = \frac{N_i}{N_k} = \frac{\omega_2 M_2}{\omega_1 M_1}
\]  

(8)

- efficiency of the transmission:

\[
\eta_s = \frac{N_s}{N_k} = \frac{\omega_2 M_2}{\omega_1 M_1}
\]  

(9)

- efficiency of the comminution process:

\[
\eta_s = \frac{E_{\text{mill}}}{E_k}
\]  

(10)

where: \( E_{\text{mill}} \) is the unit energy consumption for quasi-cutting in the conditions of the physical model to a defined form of the comminuted
ryes and plastics product, kJ·kg⁻¹; \( E_p \) is the unit energy consumption for quasi-cutting in machine conditions, kJ·kg⁻¹; \( N_e \) is the electric power supplied to the motor, W.

**Evaluation of the obtained results**

The energy efficiency of rye and plastic grinding/processing is determined similarly. The input energy of processing \( E_{in} \) is the sum of the energy contained in the charge material \( E_{mat} \) and the energy supplied to it \( E_{net} = E_{net1} + E_{net2} \). The energy at process output \( E_{out} \) is reduced by the energy losses \( E_L \) [Flizikowski and Kopacek, 2007; Cempel and Natke, 2002]:

\[
\eta_p = \frac{E_{out}}{E_{in}} = \frac{E_{net} - E_L}{E_{net} + E_{net2}} = \frac{E_{net1} - E_L}{E_{net1} + E_{net2}} \tag{11}
\]

In the case of processing efficiency, the instantaneous values and the values occurring over the longer term are important. The mean value of the energy efficiency (or the mean energy efficiency) is sometimes called the energy efficiency [Flizikowski, 2002; Flizikowski, 2011; Flizikowski and Bielinski, 2012; Flizikowski and Kopacek, 2007; Flizikowski and Lis, 2007; Kazimierzczak et al., 2004; Macko, 2000], but this is only justified when both efficiencies are equal, e.g. in the case of auto thermal extrusion.

The constructive features of the working set of the multiple disc seed mill should be selected in such a way that the function achieves the minimal value (because of the value of the unit energy consumption indicator \( E_p \)) [Ostwald, 2002].

The point where the function value fulfills the required criterion (Tab. 1) is called problem solution: \( x^* = (x_{1}^*, \ldots, x_{n}^*) \). The solution is, of course, from the permissible area: \( x^* \in \Phi \).

Tab. 1. Energy, effectiveness and efficiency grinding characteristics of biomaterials and plastics waste

<table>
<thead>
<tr>
<th>Estimators of grinding development</th>
<th>Plastics waste, PP</th>
<th>Bio-materials, rye</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption of grinding machine, ( E_p ), kJ·kg⁻¹</td>
<td>65,54</td>
<td>13,78</td>
</tr>
<tr>
<td>Effectiveness of multi-disc grinding [Zawada, 2005], ( \eta_{re} )</td>
<td>68,7</td>
<td>116,1</td>
</tr>
<tr>
<td>Material efficiency of the conversion process [Zawada, 2005], ( \eta_{re} )</td>
<td>0,14</td>
<td>0,13</td>
</tr>
<tr>
<td>Efficiency of grinding process, ( \eta_{re} )</td>
<td>0,06</td>
<td>0,11</td>
</tr>
<tr>
<td>Energy efficiency of grinding and thermo processing [Macko, 2000], ( \eta_{re} )</td>
<td>0,28</td>
<td>0,27</td>
</tr>
</tbody>
</table>

The principle of the support in the direction of getting the extreme solution can be defined [Flizikowski and Lis, 2007]:

\[
\{x^* \in \Phi \mid \exists \delta > 0, \exists \delta > 0, \exists Z(x^*) \geq Z(x')\} \tag{12}
\]

in the case of minimization of energy consumption (Z = \( E_p \)).

If the target point is known in the target space (e.g. \( E_p < 20 \) kJ·kg⁻¹ and/or \( e_g > 80 \)), it is possible to conduct the procedure aiming at approaching the given solution [Kazimierzczak, et al., 2004].

Given from experimental investigations results make up principles to shows selection onto settlement regarding to most suitable way of disintegration and solutions estimation of energy, work, effectiveness, energy consumptions and loads (Tab. 1).

**Solution**

We attribute a great part to creative individuality- building, to aiding formation processes, by modern systems of grinding design development, design engineering, production, operation, recirculation, tests and estimation. A specific area of coexistence of the biomaterials (B-m), plastics-waste (PP-w), machinery construction and grinding parameters (LT, LO, LR, PK, PR, PLOT, PLOR, PPMT, PMPM, GPK, ST) is the engineering of biomaterials, plastics wastes break-up in recycling process (Tab. 2).

Based on this study, the following specific conclusions can be drawn. There exists discrepancy between the calculated construction indicators and energetic efficiency indicators – determined for the machine built on the basis of the carried out support procedures. The discrepancy achieves the value of even several percent (the obtained result is the most advantageous when the discrepancy between the calculated construction and the constructed biomaterials mill with the energy – consumption \( E_p = 13,78 \) kJ·kg⁻¹ – with the criterion \( E_p < 15 \) kJ·kg⁻¹ is -8,13%).

The results of the so carried out experiment will make-up data concerning the process and material which will be used to assist the designing of the multiple disc cutting mills for rye or plastics grain particles.

Tab. 2. The biomaterials (rye) and PP-waste grinders parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>New solutions, grinders conception</th>
<th>PP-w</th>
<th>B-m</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT</td>
<td>Number of shields, -</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>LO</td>
<td>Number of openings in the first row of the first shield, ( \eta_{re} )</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>LR</td>
<td>Number of rows, -</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>PK</td>
<td>Angular velocity, rad·s⁻¹</td>
<td>7,34</td>
<td>12,83</td>
</tr>
<tr>
<td>PR</td>
<td>Row radius, m</td>
<td>0,065</td>
<td>0,065</td>
</tr>
<tr>
<td>PLOT</td>
<td>Increase of the number of openings between shields, -</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>PLOR</td>
<td>Increase of the number of openings between rows, -</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>PPMT</td>
<td>Increase of the radius of rows between shields, m</td>
<td>0,003</td>
<td>0,003</td>
</tr>
<tr>
<td>PPMR</td>
<td>Increase of the radius of rows in a shield, m</td>
<td>0,002</td>
<td>0,002</td>
</tr>
<tr>
<td>GPK</td>
<td>Angular velocity gradient, rad·s⁻¹</td>
<td>2,00</td>
<td>1,50</td>
</tr>
<tr>
<td>ST</td>
<td>Shields’ diameter, m</td>
<td>0,255</td>
<td>0,400</td>
</tr>
</tbody>
</table>

**Summary**

In the process of searching for processing machines properties, it is necessary to include the following procedures: to use the scientific basis of machine construction and exploitation, to create new solutions on the basis of individual ideas taking into consideration the nature of needs and the up-to-date condition of possibilities, motivations, know-how, capital, outlet, to take into consideration the complexity of technical systems to implement the stated processing function – steering, drive, service, repairing, power supply, damages, scrapping and others.

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