Research on Load on the Roll Press' Shafts and Work Items

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Abstract. The results of a method used in evaluating the load on roll press' shafts used in briquetting fine-grained materials are presented. The research was conducted in the Manufacturing Systems Department at AGH University of Science and Technology in Kraków. The research provided an insight into choosing a power plant and design features of the roll press and determining the processing parameters.

1 Introduction

Roll presses are used in briquetting/consolidating loose material. They are most frequently used in pharmaceutical, energy, metallurgical, chemical, agricultural and food industries. Assessing the roll presses' work items' maximum load is incredibly important, which can be problematic as the roll presses manufacturers are very reluctant to share the aforementioned specifications. Research on this topic mostly focuses on the briquetting process of powdery materials in roll presses equipped with screw-feeders and vertically positioned rolls itself, which is yet another obstacle in assessing the maximum load [1,4]. In Poland, most of the briquetting machinery is equipped with horizontally positioned rolls and for that reason indepth empirical, theoretical and technical analyses of i.a. torque or unit pressure on forming cavities developed during briquetting processes have been conducted in Department of Manufacturing Systems AGH for years. Selected results used in designing screw-feeder equipped PW 500 presses and work rolls stands are discussed in this article.

2 Determining the torque value

Determining the rolls' load during briquetting of loose material is vital in assessing the briquetting process. The methodology behind it is based upon mathematical modelling or real object's analysis. The former is used intends to reduce both time and costs of introducing new technologies. Mathematical modelling was used by J. Johanson in 1965 [9] in assessing the plain rolls' load. He assumed that the compacted loose material was isotropic, cohesive and homogenous, and that there was no slip between the loose material and the rolls. However, M. Hryniewicz suggests that there are certain limitations in Johanson's works [11]. M. Hryniewicz based his reservations on the flow theory presented in J. Johanson [9] and W. Herrmann's [12,13] works, which overlooked the factor of forming areas that separate cavities in the forming rings. He decided to briquette loose material in so called "makeshift work rolls layout" which allowed him to compare the total volume of forming cavities in the briquetting machine's work rolls with the volume of flattened loose material in the makeshift layout. This led to establishing a relationship (1) between the rolls' radiuses in the real and makeshift layouts.

$$R_0 = \sqrt{R^2 - \frac{i_B V_B}{2\pi B}} \tag{1}$$

Where R_0 is roller radius in the makeshift layout, R is real roller radius, i_B is number of roller forming cavities, V_B is briquette volume, B is roller active width.
He also stressed the importance of a proper compacting layout setup in the briquetting process. Based on V. P. Katashinski's [14] work, M. Hryniewicz sectionalised a part of volume of the briquetted material that was confined by the rollers' lateral planes and two planes (with infinitely short distance value *dy* [fig.1] between them) perpendicular to the displacement direction.

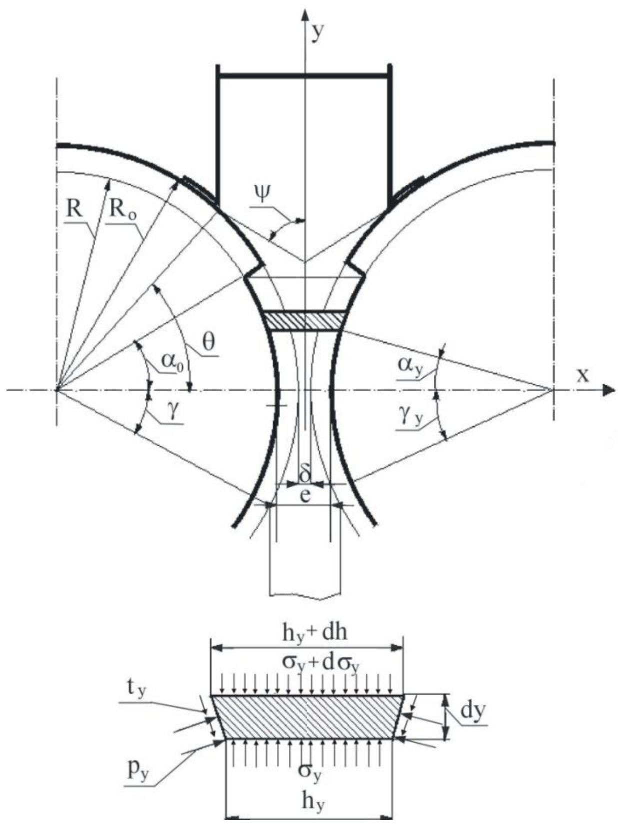

Fig. 1. Schematic of an idealised model of a roll press's compacting layout [11]: α_0 - nip angle, α_y - densification angle, γ - complete release angle, γ_y - briquettes' release angle, δ - width between rollers, θ - entry zone angle, Ψ - material insertion angle, e - slot width between rollers in the makeshift layout, R_o - roller radius in the makeshift layout, R - real roller radius.

Unit friction force t_y on rollers' surface is defined as a product of kinetic external friction μ_k - a variable dependent on the degree of compaction and moisture content of the material - and unit pressure p_y:

$$t_y = \mu_{(s,w)}\, p_y \tag{2}$$

Basing on the Tresca criterion, Hryniewicz suggested using the following yield criterion in the case of compacting fine-grained material in a roll press:

$$\sigma_1 - \sigma_2 = \vartheta \tag{3}$$

where σ_1 is major principal stress (y), σ_2 is minor principal stress (x), ϑ is unit compacting resistance.
Unit compacting resistance is defined as a variable dependent on compacting degree and moisture content of the compacted material. It's value is changeable depending on the compacting phase of the material, which takes place in a closed cylindrical matrix (with a comparable ratio of the briquette's transverse diameter to its height). On the assumption that $\sigma_1 = p_y$ and $\sigma_2 = \sigma_y$ the yield criterion can be described with the following formula [11]:

$$p_y - \sigma_y = \vartheta \tag{4}$$

By inserting dependence (2) and (4) into equation (5):

$$h_y\, d\sigma_y + \sigma_y\, dh_y - p_y\, dh_y + t_y \frac{dh_y}{tg\alpha_y} = 0 \tag{5}$$

and substituting the nip arc with a chord, Hryniewicz came up with the following equation:

$$\frac{dp_y}{dh_y} + p_y \frac{\mu_k\, ctg(\alpha_0 / 2)}{h_y} = \frac{\vartheta}{h_y} + \frac{d\vartheta}{dh_y} \tag{6}$$

All of these methods require determining value of certain physical quantities, i.a. unit compaction resistance υ, internal friction coefficient ξ, external friction coefficient μ_k, or unit pressure p_n in a function of compacting degree s, through experiments. Empirical formulas $\upsilon = f(s)$ and $\mu_k = g(s)$ facilitate determining the load on a shaft during the briquetting process of a loose material through the empirical simulation method. The same method can be used for determining the torque on a shaft of a roll press *M:*

$$M = R_0 \text{ x} \int_{\alpha_0}^{\gamma} t(\alpha)\, d\alpha \tag{7}$$

where $t(\alpha)$ is friction force function, α is angle of rotation.
Using the measuring circuit in order to continuously record the transient responses can help in determining the torque on a shaft of a roll press by analysing the results of aforementioned tests on a real object. The Department of Manufacturing Systems AGH uses telemetry method in such tests.

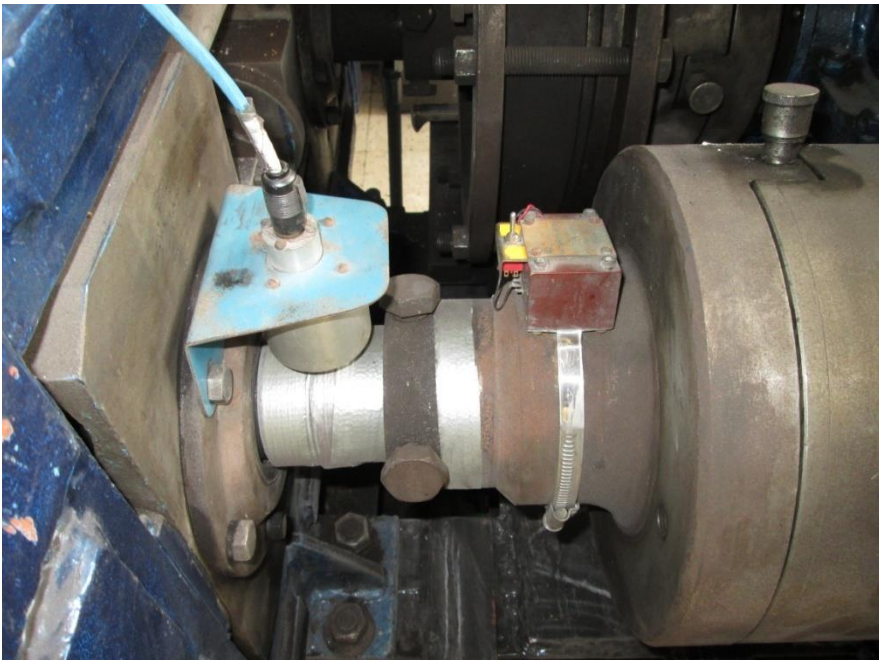

Fig. 2. The photo of a laboratory shaft of a roll press on which the torque was measured.

Power demand N_b for a LPW 450 roll press can be determined by the following relationship:

$$N_b = \frac{2 M_t \, n_w}{9{,}55} \tag{8}$$

where M_t is torque moment on a roll press, n_w is roll press rotational speed.
Value of the torque on a shaft of a roll press M_t is calculated by selecting an average inside a selected load course in a integration range [t_1, t_2] with the following formula [18]:

$$M_t = \frac{\int_{t_1}^{t_2} f dt}{t_2 - t_1} \tag{9}$$

where f is a function of the torque.
The torque calculations M_t can be used in determining unit energy demand of briquetting process Z_b with the following formula [18]:

$$Z_b = \frac{N_b}{W_b} \tag{10}$$

where W_b is roll press throughput.

Exemplary LPW 450 roll press equipped with gravity feeder torque characteristic M_t is presented in fig. 3.

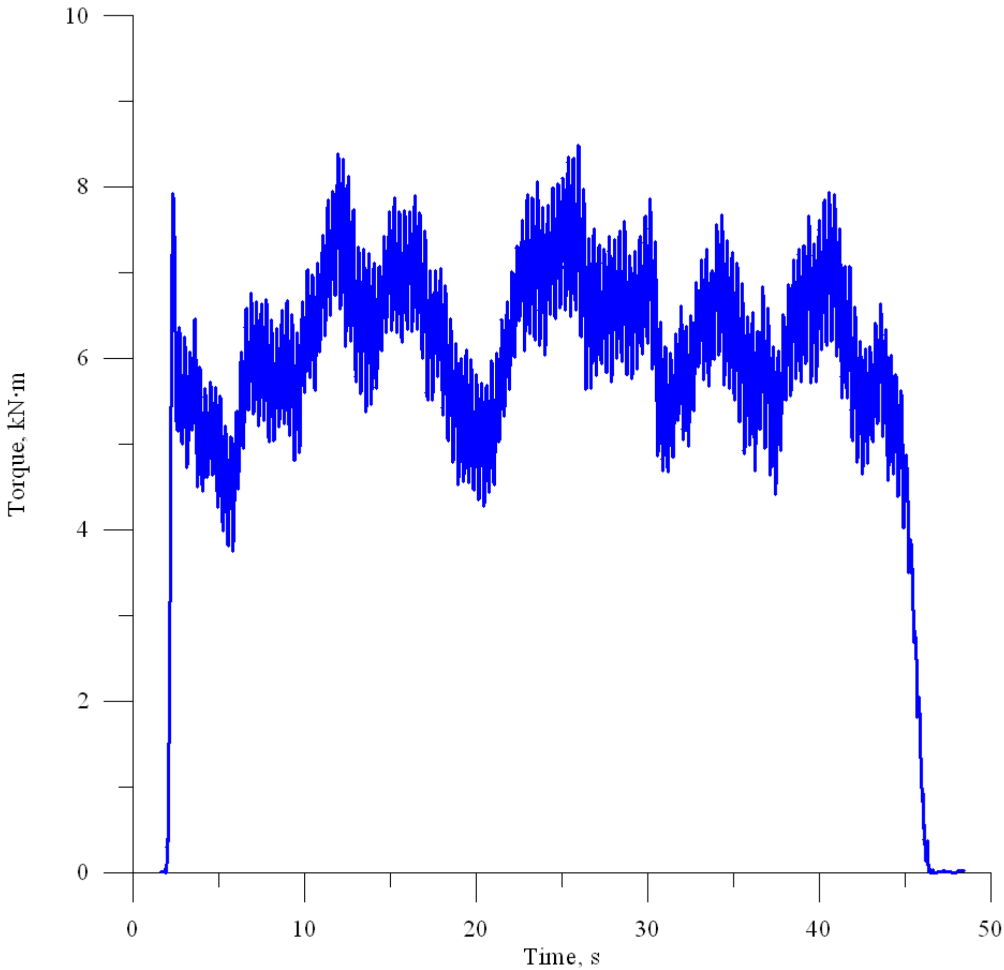

Fig. 3. Transient characteristic of torque on a LPW 450 roll press equipped with a gravity feeder shaft during briquetting of lead waste, burnt lime and treacle mixture [17].

3 Defining unit pressure value

Unit pressure applied on the forming cavity by the compacted loose material puts a significant load on the forming rolls stands. Its value depends on the setup of the compacting layout, its design and the compacted material characteristics. J. Johanson was the first one to discuss the importance of nip angle α_0 [9] and his work was later used as a cornerstone for further research. M. Hryniewicz, thanks to his research on briquetting copper concentrate with an addition of sulphite lye mixture oraz colliery shale with an addition of sulphite lye, highlighted a significant discrepancy between the results achieved based on J. Johanson's method and those obtained in a laboratory [11]. He suggested using the following nip angle formula:

$$\alpha_0 = arc\cos\left[1 - \frac{\left(\frac{i_b V_b}{2\pi R B} + \delta\right)(S_b - 1)}{2\left(R - \frac{i_b V_b}{4\pi R B}\right)}\right] \tag{11}$$

where δ is width between rollers in the makeshift layout, s_b is the briquette compaction degree.

Unit pressure course measurements were conducted in various scientific centres [10, 21-22, 24-27] and aimed at optimisation of the compacting process of pharmaceuticals in a roll press equipped with smooth rollers [1]. In order to assess a theoretical unit pressure course for compacted material, such as municipal sewage sludge, the nip angle α_0 value as well as case-specific empirical formulas $\vartheta = f(s)$ and $\mu_k = g(s)$ [18] must be determined.

Using screw feeder instead of gravity feeder can increase the unit pressure in a forming cavity. The screw feeder has functions that make two zones: feeding & homogenisation; and initial compaction. Material feeding and homogenising is achieved by using the catcher and first screw coil. The initial compaction zone includes the section from the first to the last screw coil. In this zone the material is initially vented. It is also affected by the proper screw and cylinder surface shape. The cylinder should be constructed so that resistance caused by friction between moved fine-grained material and its wall is as big as possible [2-3]. Such situation takes place when cylinder walls are grooved. In that case the flowing fine-grained material fills the grooves. In consequence internal friction occurs on the surface where fine-grained material and the cylinder are in contact. In contrast to the cylinder walls the frictional resistance on the screw surface should be as low as possible. Hence, the surface roughness of the proper feeder working element should be taken into consideration. Cylindrical and tapered screws with fixed or variable stroke are used. Depending on the width of working rollers, the screw feeder is equipped with one or several working elements [15].

Properly setup kinematic parameters of the roll press and screw feeder's working elements results in better compaction of the loose material due to increased material flow. Forced feed/power supply increases rotational speed of the rolls which translates into better efficiency (due to enhanced unit pressure on the forming cavity) without loss of the briquettes' strength parameters. There are also other benefits of using screw feeders, such as grinding down the material for more effective briquetting or homogenisation processes. Friction caused by the grinding down process results in an increase in the temperature that activates the binders inside the loose material, which leads to stronger intergranular bonding during the compaction process.

Selecting a proper rotational speed of the screw feeder is vital in the process of material compaction in the roll press. In order to determine it a specific condition of fixed mass flow through the screw feeder and roll press was considered. The condition is:

$$Q_m = W_m \tag{12}$$

where Q_m is mass flow rate of the screw feeder, W_b is mass flow rate of the roll press.

Substituting for Q_m [16]:

$$Q_m = 15 z \pi^2 \left(D_z^2 - D_w^2\right) D_m n_{sl} \frac{\tan\beta \tan\varphi_m}{\tan\beta + \tan\varphi_m} \rho_w \tag{13}$$

where z is number of screws, D_z is external screw diameter, D_w is internal screw diameter, $D_m = (D_z + D_w)/2$, n_{sl} is screw rotational speed, β is angle of flow of fine-grained material in the screw feeder, φ_m is average inclination angle of the screw line, ρ_w is density of the material flowing out of the screw feeder,

$$W_m = 60\, V_b i_b n_w \rho_b \tag{14}$$

where V_b is briquette volume, i_b is number of forming cavities, n_w is press roller rotational speed, ρ_b is briquette density,
a dependence was obtained (15) that allows for the calculation of the screw rotational speed:

$$n_{sl} = \frac{60 V_b i_b n_w \rho_b \left(\tan\beta + \tan\varphi_m\right)}{15 z \pi^2 \left(D_z^2 - D_w^2\right) D_m \tan\beta \tan\varphi_m \rho_w} \tag{15}$$

The compaction degree acquirable in the zone between the press rollers is:

$$s_b = \frac{h_p}{e} \tag{16}$$

where h_p is the distance between replacement rollers at the nip angle level that determines the beginning of material compacting.
The quotient of the volume density and the material flowing out of the screw feeder is the degree of compaction achieved in the zone between rollers. Taking this into consideration and using the formula (15) we have a dependence (16) that is used to calculate the density of material flowing out of the screw feeder.

$$\rho_w = \frac{\rho_b\, e}{h_p} \tag{17}$$

Own observations of the benefits of using the screw feeder in the roll press assembly were presented in fig. 4. It enables increasing the nip angle α_{sl} from several to tens of percent in comparison to the gravity feed α_g. It causes increase in the time of pressure on the compacted material and the growth of its maximum value p_{max}. It can be assumed that the complete release angle $\gamma_{sl} = \gamma_g$ under condition that the use of gravity feed enables achieving proper briquettes with satisfactory mechanical strength.
Higher unit pressure value in the forming cavity is caused by better compaction of the loose material. In this particular case, the compaction degree s acquirable in the roll press equipped with the screw feeder is determined by the following dependence:

$$s = s_w s_b \tag{18}$$

where s_w is initial compaction degree in the feeder.
The test results of material flow in gravity feeder conducted in Slovak University of Technology in Bratislava [20, 23] with the help of a CCD camera also backup the assumption presented in fig. 4.

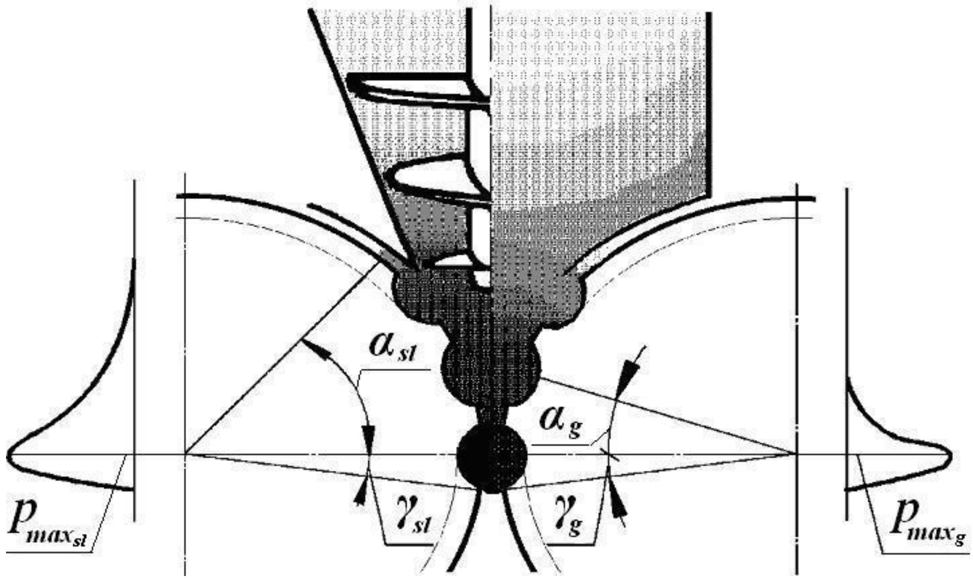

Fig. 4. Diagram showing the influence of the feeder (left side: screw feeder, right side: gravity feeder) on the nip angle value and unit pressure in the roll press forming cavity [15].

Figure 5 presents test results of a computer simulation which aimed at determining unit pressure characteristics of loose material of varying moisture *m* compacted in a roll press equipped with gravity feeder.

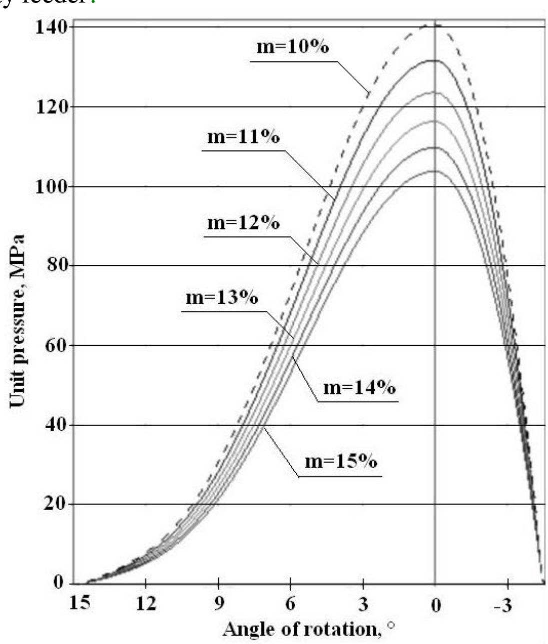

Fig. 5. The impact of moisture content of composite solid fuels on the unit pressure course during a computer simulation of briquetting process in a LPW 450 laboratory press with width between the rollers $\delta = 1$ mm and briquette volume $V_b = 6{,}5$ cm^3 [5-8].

Load on the forming rollers stand of a briquetting machine equipped with 450 mm diameter rollers was analysed at Department of Manufacturing Systems AGH. Unit pressure on the forming cavity of the compacted waste sludge was measured with a strain gauge membrane sensor (fig. 6) and Hottinger Baldwin Messtechnik stain gauge amplifier MTG 232.

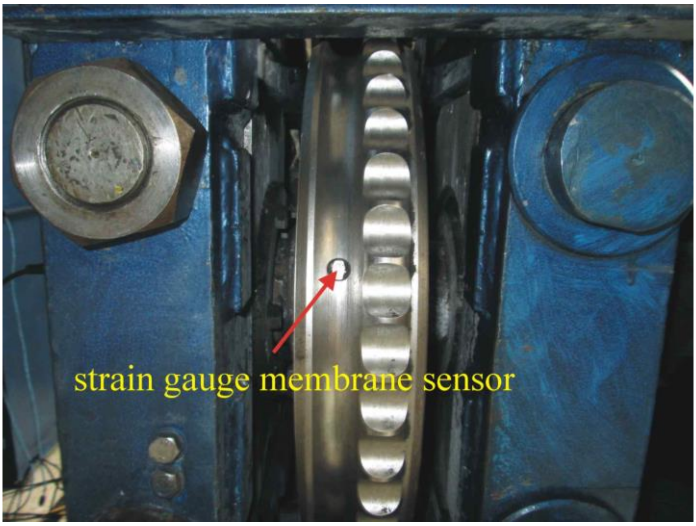

Fig. 6. LPW 450 laboratory roll press forming ring equipped with a strain gauge membrane sensor.

The signal from the sensor was sent through a wire to a measuring socket and then registered on a PC through a strain gauge amplifier. Unit pressure transient performance during the briquetting of glass-making raw materials mixture in a LPW 450 roll press equipped with a screw feeder is presented in fig. 7.

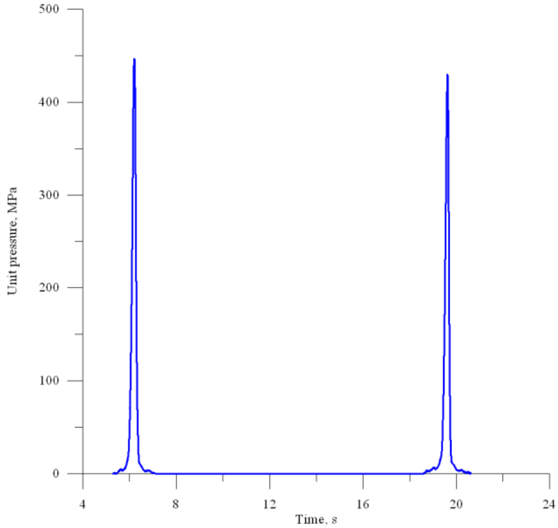

Fig. 7. Unit pressure transient performance measured performance during the briquetting of glass-making raw materials mixture in a LPW 450 roll press equipped with a screw feeder [19].

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An increase in value of the nip angle α_0 due to usage of screw feeder was confirmed by the results obtained in Department of Manufacturing Systems AGH. Constant load caused q_r by unit pressure can be determined with the following formula [18]:

$$q_r = \pi \frac{(\alpha_0 + \gamma)}{180^\circ} R_o \frac{\int_{\alpha_0}^{\gamma} p(\alpha) d\alpha}{\alpha_0 - \gamma} \tag{19}$$

4 Conclusion

Based on the conducted experiments, the load on the shafts of the roll presses during the briquetting process was determined, which allowed for an update of the main drive of the roll press PW 500. The update is based on using the motor reducer Drive 6000 CHHMS75-6265-59/T F1250S/6 (i.e. electric motor with power equalling to N_m = 55 kW and nominal rotational speed n_n = 980 rpm, and reducer type 'CYCLO' with gear ratio i = 59). The rotational speed is controlled by the frequency converter FRA 540LG75KE1 (of Mitsubishi Electric). Apart from that, the PW500 roll press is equipped with a screw feeder, complete with Danfoss Power Solutions DH 400 hydraulic motor (motor parameters: max. power N_{max} = 5,5 kW, max. torque M_t = 410 N·m, max. rotational speed n_{sl} = 155 rpm). Scheme of a PW 500 roll press equipped with a screw feeder is presented in fig. 8.

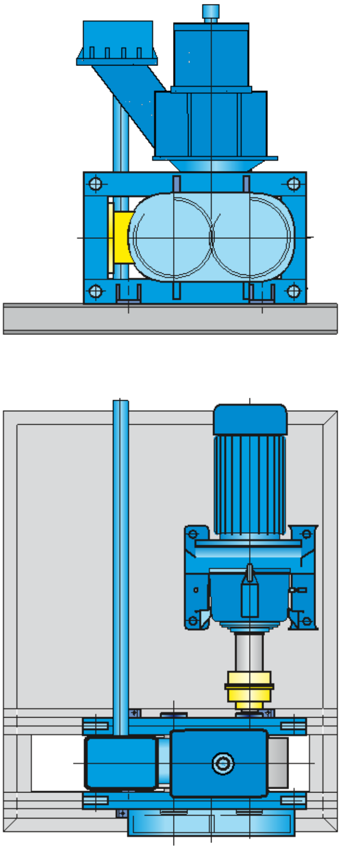

Fig. 8. PW 500 industrial roll press after modernization.

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