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KINEMATIC MODEL FOR FORMING DOUGH INTO CYLINDRICAL SHAPES

This study presents a description of the mechanics of forming dough pieces into cylindrical (cylinder-like) shapes. Based on the configuration of forming, the movement of the formed piece and its surface deformations were described. Kinematic relationships concerning the dough piece material as a rheological fluid were formulated. Next, the relationships coupling the kinematic quantities present with both descriptions were determined. The components of the deformation rate tensor, presented in the assumed forming configuration (cylindrical coordinate system), describe the velocity distribution on the surface of dough piece being formed and deformed. The determined kinematic quantities and their interrelations may be used to describe the process of forming dough pieces into cylindrical shapes.

1. Introduction

The difficulty of manual work and its low productivity during bread production, the consumption and production volume of bakery products as well as the changes as to the type of bread consumed make it necessary to use mechanized methods and ways of producing bread at each stage of the technological process.

The formation of dough pieces is one of the vital technological operations during the production of any bakery products. The shapes of dough pieces (and, subsequently, of bakery products) follow local habits, customs and customer preferences.

The following basic shapes of dough pieces are used in the production of bakery products [1], [2], [6]:

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– Flat (flattened),
– Cylindrical (cylinder-like),
– Spherical (ball-like).

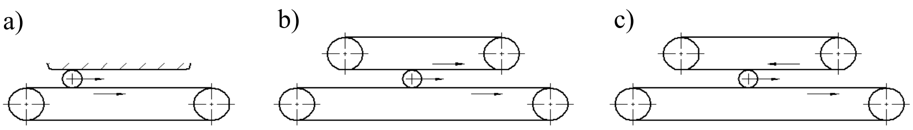

Fig. 1. Diagram of forming dough pieces into cylindrical shapes

The subject of this study is forming of dough pieces into cylindrical shapes, which is used in the production of bread loaves and long bread rolls (bar-shaped bread rolls, baguettes).

Cylindrical shapes are obtained using the methods of forming presented in Fig. 1, a), b), c), which refer to the manual methods but are executed by means of suitable machinery. The most common machines used for forming cylindrical shapes in cooperation with the dough dividing machine include: the two – belt rounder machine and the belt elongating machine.

In designing and constructing the forming machines, one needs to know the relationships between the kinematic and dynamic quantities, as well as the material properties existing during formation of dough pieces, which is necessary for correct and effective selection of the working parameters of the machines.

This study is an extension of the subject of forming dough into spherical pieces presented in paper [1] applied to the assumed cylindrical geometrical configuration of dough pieces. We make use of the previously described method and way of treating the subject.

2. The kinematics of forming

Forming a dough piece is based on moving it adequately inside the forming space of the machine between the working surfaces (Fig. 1). In the process of forming, a dough piece undergoes reshaping (without any change of its weight and volume – constant density, incompressibility) from the initial shape (usually an irregularly shaped chunk formed by dividing the dough into pieces) to the final cylindrical (cylinder-like) shape [1], [4]. The material of dough piece being formed undergoes deformations caused by the piece-shifting motion and the motion-causing forces.

The discussion concerning the process of forming a dough piece was limited to the description of the influence of the field of the mechanical (kinematic) quantities. Since the forming process is short (a few to several seconds) and the thermodynamic quantities (temperature, heat exchange) are practically steady, the influence of non-mechanical (thermal and biochemical) quantities was disregarded.

2.1. Forming configuration

The formation of cylindrical shapes may take place in two cases (similarly as it was shown in Fig. 2.1 and 2.2 in paper [1]):

– both working surfaces make the forming movement - in the opposite direction (Fig. 1 c) or the same direction (Fig. 1 b) – diagram of operation of the rounder machine with two belts,
– only one surface makes the forming movement (Fig. 1a) and the other one is fixed – diagram of operation of the belt elongating machine.

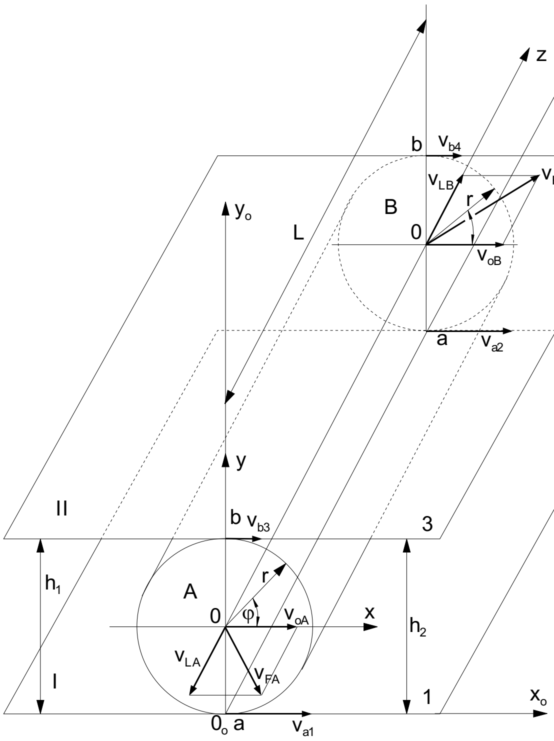

Fig. 2. The configuration of forming cylindrical shapes between moving working surfaces I and II

In order to determine the relationships between the kinematic quantities describing forming of a dough piece, a geometrical configuration (Fig. 2) was designed and used as a model for forming a piece based on the presented simplified method of forming a piece into a cylindrical shape between two flat working surfaces.

The forming configuration presented in Fig. 2 has a steady (Cartesian coordinate) reference system (x_o, y_o, z_o), whose origin is located at the point of contact (a) of the dough piece with the forming surface (I). The points of contact (a) and (b) are where the forming velocities are attached at the end of the radius vector r and simultaneously on the surface of the rolled dough piece. A movable Cartesian coordinate reference system (x, y, z) is placed in the center (0) of the piece being formed (the geometrical center of the cylinder), on the end face of the cylinder marked (A). Its origin moves at the velocity of v_o between the working surfaces (I) and (II). The surfaces (I) and (II) are, in fact, convergent (opposite to the direction of the piece motion), and the gap between the surfaces is determined by the quantities h_1 and h_2, described by the relationships:

$$h_2 > h_1 \tag{1}$$

and

$$h_1 = 2r_k, \tag{2}$$

where: r_k – final radius of the formed cylindrical piece.

In the center (0) there is also the origin of the system of cylindrical coordinates (r, φ, z). In this system the position of the radius vector r is determined by the φ angle (with the x-axis). While forming, the value of the φ angle is a function of own revolutions n_k of the piece, in the following form:

$$\varphi \in (0, \pi n_k)\,. \tag{3}$$

The changing (current) value of the r radius may take values within the range determined below:

$$r \in \left(\frac{h_2}{2}, r_k\right). \tag{4}$$

The points of contact of the piece with the forming surfaces (I) and (II) change their coordinates in the system of cylindrical coordinates circulating around the whole cylindrical surface of the piece until it is formed, i.e. when it reaches the required final dimensions:

$$r = r_k \quad \text{where} \quad L = L_k, \tag{5}$$

where:

L – current length of the cylinder's generating line between the end faces (A) and (B), changing with the velocity of $2v_L$ during forming,

L_k – final length of the generating line between end faces (A) and (B) of the formed cylindrical pieces.

The piece being formed has the volume determined for a cylinder as follows:

$$V = \pi r^2 L = \pi r_k^2 L_k, \tag{6}$$

where: V – volume of the piece being formed, invariable during forming (as a result of assuming incompressibility of the piece).

The change in the lateral dimensions of the piece (decrease of its radius r) is accompanied by a change in the piece length (elongation) as a result of preserving the piece volume with the assumed incompressibility of the piece material. The changeable (current) dimension L of the piece length is defined by the following relationship:

$$L \in (L_0, L_k), \tag{7}$$

where: L_0 – initial piece length (with initial radiusr_0), L_k – final piece length (with radius r_k).
The final piece length (from the condition of preserving its volume), is:

$$L_k = L_0 \frac{r_0^2}{r_k^2}. \tag{8}$$

Figure 2, which describes the configuration of forming, serves as a basis for determining relevant kinematic quantities during cylindrical forming.

2.2. Kinematic relationships in cylindrical forming

Based on kinematic analysis of Figure 2, considering the symmetrical interaction of the present velocities, it is possible to determine the elongation velocity $2v_L$, active in the center (0) on the axis (z) of the cylindrical piece, in a general form:

$$2v_L = \frac{L_k - L_0}{t} = \frac{\Delta L}{t}, \tag{9}$$

where: ΔL – increase in length of the cylinder's generating line of the piece being formed, t – piece forming time.
The velocity $\mathbf{v}_L$ is also determined by the relationship:

$$\mathbf{v}_L = |\mathbf{v}_{LA}| + |\mathbf{v}_{LB}|. \tag{10}$$

The geometrical relationships presented in Figure 3 are used to determine the velocity components applied to the relationships.

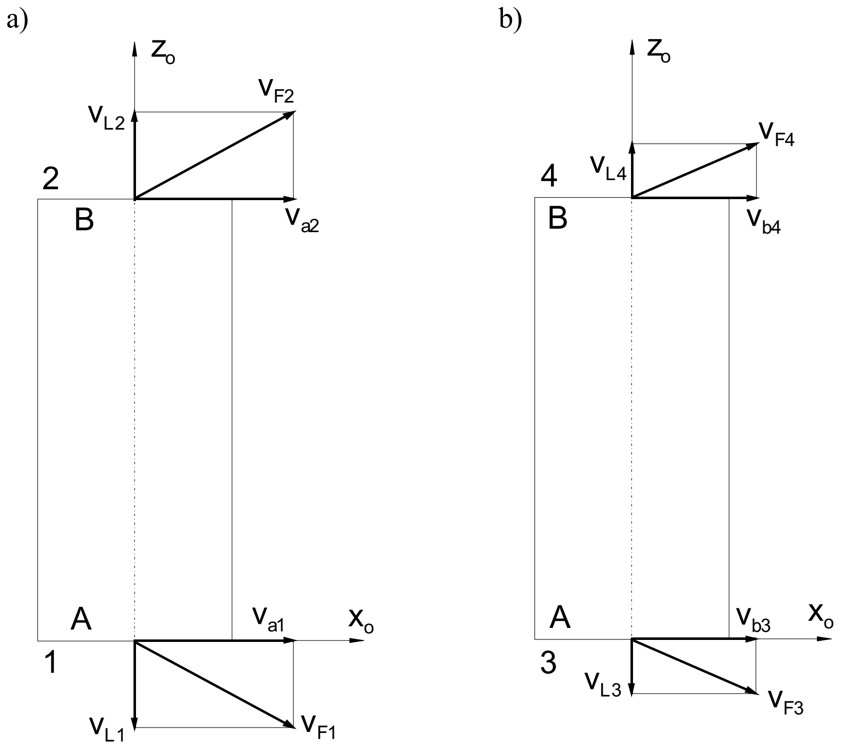

Fig. 3. Distribution of forming velocities over the working surfaces, a) lower I, b) upper II

Analysis of Figures 2 and 3 makes it also possible to determine the other velocities active in the center (0) on the axis (z) of the cylindrical piece, namely:

$$\mathbf{v}_{FA} = \mathbf{v}_{0A} + \mathbf{v}_{LA} = \mathbf{v}_{F1} + \mathbf{v}_{F3} \tag{11}$$

and

$$\mathbf{v}_{FB} = \mathbf{v}_{0B} + \mathbf{v}_{LB} = \mathbf{v}_{F2} + \mathbf{v}_{F4} \tag{12}$$

Next, considering the symmetry of velocity action, we can assume that:

$$\mathbf{v}_F = |\mathbf{v}_{FA}| + |\mathbf{v}_{FB}|. \tag{13}$$

On the basis of Figure 3 it is possible to derive the velocity components from the formula (10), in the following form:

$$\mathbf{v}_{LA} = \mathbf{v}_{L1} + \mathbf{v}_{L3}, \tag{14}$$

$$\mathbf{v}_{LB} = \mathbf{v}_{L2} + \mathbf{v}_{L4}. \tag{15}$$

The relationships in the figure allow us to determine the following expressions:

$$\mathbf{v}_{F1} = \mathbf{v}_{L1} + \mathbf{v}_{a1}, \tag{16}$$

$$\mathbf{v}_{F2} = \mathbf{v}_{L2} + \mathbf{v}_{a2}, \tag{17}$$

$$\mathbf{v}_{F3} = \mathbf{v}_{L3} + \mathbf{v}_{a3}, \tag{18}$$

$$\mathbf{v}_{F4} = \mathbf{v}_{L4} + \mathbf{v}_{a4}. \tag{19}$$

The components presented in the expressions (11) and (13) can be defined by the following relationships:

$$\mathbf{v}_{FA} = \mathbf{v}_{F1} + \mathbf{v}_{F3}, \tag{20}$$

$$\mathbf{v}_{FB} = \mathbf{v}_{F2} + \mathbf{v}_{F4}. \tag{21}$$

Using the relations in Figure 2, we obtain for the above expressions the following:

$$v_{FA} = v_{F1} + v_{F3} = \sqrt{v_{a1}^2 + v_{L1}^2} + \sqrt{v_{b3}^2 + v_{L3}^2}, \tag{22}$$

$$v_{FB} = v_{F2} + v_{F4} = \sqrt{v_{a2}^2 + v_{L2}^2} + \sqrt{v_{b4}^2 + v_{L4}^2}. \tag{23}$$

Thus, on the basis of the relationship (13) and the above ones, we obtain the relationship for the forming velocity in the following form:

$$v_F = v_{FA} + v_{FB} = \sqrt{v_{a1}^2 + v_{L1}^2} + \sqrt{v_{b3}^2 + v_{L3}^2} + \sqrt{v_{a2}^2 + v_{L2}^2} + \sqrt{v_{b4}^2 + v_{L4}^2}. \tag{24}$$

Regardless of the method of determination mentioned in the relationships (22)–(24), we can use the relationships from Figure 4 to determine the resultant forming velocity $\mathbf{v}_F$ in the expression (13). The diagram shows the process of rounding a cylindrical piece inside the working space between the convergent forming surfaces.

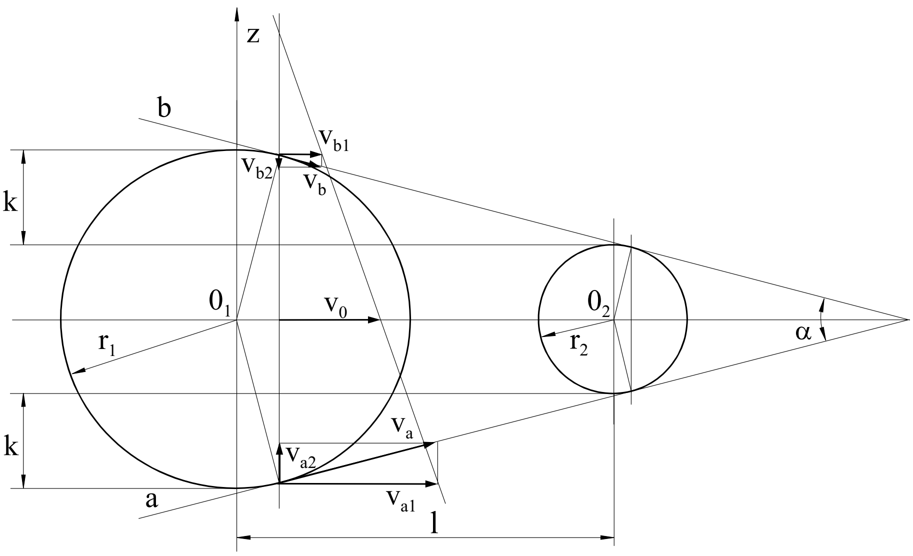

Fig. 4. The velocity of dough piece motion as a result of an action exerted by the working surfaces

The resultant forming velocity is directly determined by the relationship (Figure 2):

$$\mathbf{v}_F = \mathbf{v}_0 + \mathbf{v}_L. \tag{25}$$

The working surfaces, a) lower, b) upper are marked in Figure 4 as well as the velocities of the forming motion of these surfaces. It results from the analysis of the figure that in the most general case, the velocity of movement of the piece (its center of mass) between the working surfaces is expressed by a relationship in the following form:

$$v_o = \kappa \frac{v_a + v_b}{2} \cos \frac{\alpha}{2}, \tag{26}$$

where: v_0 – velocity of the piece center, v_a – velocity of working surface a, v_b – velocity of working surface b, κ – coefficient reducing the piece velocity as a result of the piece slip and its deformation (usually κ = 0.6 – 0.9).
From the expression (26) we can derive three possible cases of forming of a cylindrical piece [3] corresponding to the diagrams a), b), c) in Figure 1:

- if the velocity senses are equal to b), the expression (26) has the (+) mark,
- if the velocity senses are equal to c), the expression (26) has the (–) mark,
- if the velocity senses are equal to a), then respectively, for example, velocity $v_b = 0$.

This method of determining the velocity $\mathbf{v}_F$ of cylindrical forming (according to the formula (25)) makes it possible, considering the above cases of velocity distribution, to determine the forming velocity depending on the forming method as presented in Figures 1 a), b), c).

For the rotary motion of the piece between the working surfaces, we can determine the velocity on the surface of the dough piece using the already known relationship:

$$v_0 = \frac{2\pi r n_k}{60}, \tag{27}$$

where: n_k – frequency of piece's own revolutions, r – current radius of the piece.

Based on the relationship (27), it is possible to determine the frequency of piece revolutions n_k in the following form:

$$n_k = \frac{30}{\pi}\frac{v_0}{r} = \frac{15}{\pi}\frac{v_a + v_b}{r}\cos\frac{\alpha}{2}. \tag{28}$$

Figure 4 presents the change in the lateral dimensions of the cylindrical piece in two sample positions during its movement (forming) at the velocity of v_0 between the working surfaces. The distance covered by the piece for elementary quantities, is [1], [2]:

$$\int_0^l dl = \int_{t=0}^{t=1} v_0\, dt, \tag{29}$$

After substitution of the relationship (26) and integrating (at a time unit), we receive:

$$l = v_0 = \frac{v_a + v_b}{2}\cos\frac{\alpha}{2}. \tag{30}$$

The change of the dimensions of the piece k during its motion over the path l can be determined as a relationship between the elementary values of these quantities in the following form [1], [2]:

$$\int_0^k dk = \mathrm{tg}\frac{\alpha}{2}\int_0^l dl. \tag{31}$$

After integrating, it results:

$$k = l\,\mathrm{tg}\frac{\alpha}{2}. \tag{32}$$

Next, substituting the relationship (30) to the above, we receive:

$$k = v_0 tg\frac{\alpha}{2} = \frac{v_a + v_b}{2}\sin\frac{\alpha}{2}. \tag{33}$$

For small values of the angle α, it can be assumed that:

$$l \approx \pi r. \tag{34}$$

So after substituting to (32), we receive:

$$k = \pi r tg\frac{\alpha}{2}. \tag{35}$$

On the basis of the trigonometric relationships between the kinematic quantities in Figure 4, we can determine a relationship similar to (35) in the following form:

$$\frac{k}{\pi r} = \sin\frac{\alpha}{2} \tag{36}$$

and then:

$$k = \pi r \sin\frac{\alpha}{2}. \tag{37}$$

The k quantity describes the change of the piece dimensions during forming [1], [2], [6] and is the piece's deformation measure. The k quantity refers to the change of the piece's radius r during its half-turn. This is why it is called the radial deformation or half-turn deformation.

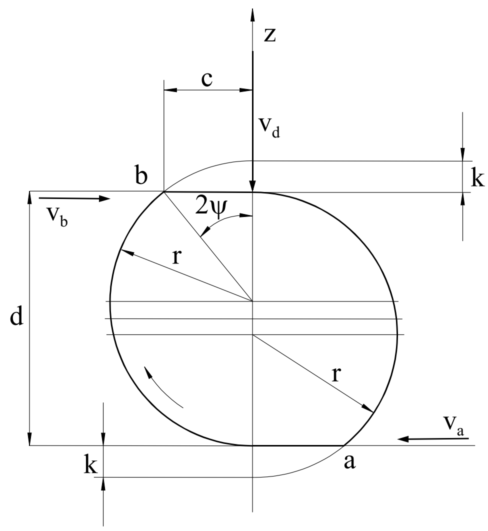

Fig. 5. Deformations and velocities on the deformed cylindrical piece

Figure 5 shows the deformed piece during its relocation between the working surfaces. The presented system models the process of deformations occurring on the piece's surface. Assuming that vector v_d in Figure 5 describes the velocity of the change of piece dimension (radius r) and that it causes radial deformation k (its half-turn over a time unit on both working surfaces), we can write:

$$\int_{t=0}^{t=1} v_d dt = 2 \int_{0}^{k} dk, \tag{38}$$

Hence, the relationship for the velocity of the change of piece dimension (piece deformation velocity) will be:

$$v_d = 2k. \tag{39}$$

Substituting to (39) a relationship (33) corrected according to Figure 5 (mark -), we receive:

$$v_d = (v_a - v_b) \sin \frac{\alpha}{2}. \tag{40}$$

Based on the analysis of the kinematics of forming, modeled in Figures 4 and 5, it is possible to determine the relationship describing the relation between the deformation k of a piece rotating with the revolution frequency n_k (there are four deformations k per one turn of the piece) and the deformation velocity v_d, in the following form [1], [2], [6]:

$$k = \frac{1}{4}\frac{60 v_d}{n_k} = 15\frac{v_d}{n_k}, \tag{41}$$

Substituting to the above the relationships (28) and (39), we receive the relationship (35).

The geometrical relationships in Figure 5 make it possible to determine the piece flattening in deformation as a surface deformation f_k in the form:

$$f_k = cL \tag{42}$$

where: c – width of deformation of the piece cylinder (measure of deformation – circumferential deformation), L – length of the piece cylinder.

The surface deformation is described by means of geometrical quantities from Figure 5, in the form:

$$c = \sqrt{r^2 - (r-k)^2} = \sqrt{2rk - k^2}. \tag{43}$$

As it results from Figure 5, there are two surface deformations f_k, described respectively by measures of deformation: k – radial and c – circumferential, per piece's half-turn.

The determined quantities of radial deformation k [2], [6], in the form (35) or (37) allow us to determine the circumferential deformation c, after application of (43), as:

$$c = \pi r \sqrt{\frac{2}{\pi} \sin \frac{\alpha}{2} - \sin^2 \frac{\alpha}{2}} \tag{44}$$

or

$$c = \pi r \sqrt{\frac{2}{\pi} \mathrm{tg} \frac{\alpha}{2} - \mathrm{tg}^2 \frac{\alpha}{2}}. \tag{45}$$

Because the value of angle α is usually small, both relationships can be treated as equivalent.

During one turn of the piece there are four surface deformations f_k – and consequently four circumferential deformations c. To cover the whole piece's circumference with deformations c, the piece should make at least n_c revolutions, therefore:

$$n_c \geqslant \frac{2\pi r}{4c} = \frac{\pi r}{2c}. \tag{46}$$

While being formed, the piece changes its lateral dimension from the initial value r_0 to the final value r_k, so the range of changes of the current radius r, will be:

$$r \in (r_0, r_w), \tag{47}$$

thus for $r_0 > r_k$, we receive:

$$\int_{r_w}^{r_0} dr = r_0 - r_k. \tag{48}$$

The necessary minimum number of piece revolutions n_r in order to obtain the dimension r_k, assuming that there are four deformations k per one piece turn, is expressed by the following formula:

$$n_r \geqslant \frac{r_0 - r_k}{4k}. \tag{49}$$

The actual number of piece's revolutions n_n necessary for its forming, results from the postulate of meeting simultaneously the conditions determined by the relationships (46) and (49), so we receive:

$$n_c \leqslant n_n \geqslant n_r. \tag{50}$$

Practice proves that in order to form a piece we usually need $n_n = 6 - 12$ revolutions, depending on the type of dough and working surfaces.

The minimum necessary distance C_k covered by the piece being formed is determined by the relationship:

$$C_k \geqslant 2\pi r n_n. \tag{51}$$

The length of the forming distance serves the purpose of determining the length of forming surfaces a and b, depending on the assumed forming diagram (Fig. 1).

In the description of forming, major significance is attributed to the deformation velocity v_d used in the kinematic relationships describing the deformations occurring during dough forming. The deformation velocity can also be determined based on the principles of the mechanics of fluids considering the rheological properties of the piece material – dough, from the relationships between the components of the deformation velocity tensor and stress tensor [1], [5].

3. Deformation velocity tensor in the forming configuration

The analysis considering rheological properties of a deformed dough piece described by kinematic quantities as presented in study [1] may also be applied to these considerations on the formation of a cylindrical dough piece.

Using the results of the studies described in item [3] concerning a few types of doughs made from wheat flour and a mixed (wheat and rye) flour, which prove that within 30 minutes of making the dough (i.e. while piece forming operations should be done), the rheological properties of such doughs are precisely enough described by the Herschel-Bulkley (H–B) power model in the one-dimensional form:

$$\tau = \tau_o + \eta \dot{\varepsilon}^{\frac{1}{m}} \tag{52}$$

and the three-dimensional one:

$$\sigma_{ij} = \left|p\delta_{ij}\right| + 2\left[\tau_o + \eta A_H^{\frac{1}{m}}\right] A_H^{-1} \dot{\varepsilon}_{ij}, \tag{53}$$

where the generalized viscosity for the H–B model:

$$\Gamma_H = \left[\tau_o + (\eta_H A_H)^{\frac{1}{m}}\right] A_H^{-1} = \left[\tau_o + \eta A_H^{\frac{1}{m}}\right] A_H^{-1} \tag{54}$$

where: A_H – deformation velocity rate (three-dimensional) for H–B model, η_H – characteristic (structural) viscosity for H–B model, m – index of power characterizing the material (dough) properties, τ_o – initial shear stress.

Formally, a form of a model expression for the examined types of dough (determined by experiment (considering the value of the Debora number [4] and consequences involved), similar to the model expression (53), can be presented analogously to the above (53) and (54), [3]:

– a functional of the generalized viscosity Γ_E based on experimental data:

$$\Gamma_E = \left(\tau_o + \tau_o A_E^{\frac{1}{m}}\right) A_E^{-1} = \left(\tau_o + \eta_o \dot{\varepsilon}_o^{\frac{1}{m}} A_E^{\frac{1}{m}}\right) A_E^{-1}, \tag{55}$$

– a mathematical model of dough properties determined by experiment:

$$\sigma_{ij} = \left|p\delta_{ij}\right| + 2\Gamma_E \dot{\varepsilon}_{ij} = \left|p\delta_{ij}\right| + 2\left(\tau_o + \eta_o \dot{\varepsilon}_o^{\frac{1}{m}} A_E^{\frac{1}{m}}\right) A_E^{-1} \dot{\varepsilon}_{ij} \tag{56}$$

where: A_E – deformation viscosity rate based on experimental data, $\dot{\varepsilon}_o$ – initial deformation viscosity.

To determine the deformation velocity rate A_E, it is possible to use in the above relationships an expression in a general form:

$$A_E = \left| 2\dot{\varepsilon}_{ik} \cdot \dot{\varepsilon}_{ki} \right|^{1/2} \tag{57}$$

From previous studies by the author [3], it results that the range of variability of the indexes and initial values in the above relationships is the following:

$$\begin{aligned}
&\frac{1}{m} \in (0.1496 - 0.2285); \\
&\eta_o \in (3385 - 5482); && \text{Pa s,} \\
&\dot{\varepsilon}_o \in (4.3351 - 7.2357); && s^{-1}, \\
&\tau_o \in (7.85 - 12.26); && \text{kPa.}
\end{aligned}$$

In order to describe the deformations occurring in the fluid it is necessary to determine the components of the deformation velocity tensor in the adopted system of cylindrical coordinates from Figure 2. To do this, it is necessary to transform the tensor components from the generalized orthogonal system of curvilinear coordinates (q_1, q_2, q_3) to the system of cylindrical coordinates (r, φ, z). The cylindrical coordinates in the Cartesian coordinate system (x, y, z) are described by the following relationships:

$$r = \sqrt{x^2 + y^2}, \tag{58}$$

$$x = r\cos\varphi, \tag{59}$$

$$y = r \sin\varphi, \tag{60}$$

$$z = z. \tag{61}$$

After changing from the notation in the generalized triple orthogonal linear coordinates system to the notation in the cylindrical coordinates and after determining Lame coefficients in this system, the components of the deformation velocity tensor are described by the following system of relationships which is analogous with the one contained in paper [1]. The components v_r, v_φ, v_z, of the forming velocity v_F, shown in these relationships for the cylindrical coordinate system, result from the interrelations between these velocity components in the system (x, y, z) as a result of an analysis of Figures 2 and Fig. 3.

The deformation velocity rate A_E (modulus of deformation velocity deviator) is expressed in cylindrical coordinates as follows:

$$A_E = \left[2\left(\dot{\varepsilon}_{rr}^2 + \dot{\varepsilon}_{\varphi\varphi}^2 + \dot{\varepsilon}_{zz}^2 + 2\dot{\varepsilon}_{r\varphi}^2 + 2\dot{\varepsilon}_{\varphi z}^2 + 2\dot{\varepsilon}_{zr}^2\right)\right]^{\frac{1}{2}}. \tag{62}$$

Taking into account rheological properties of dough by applying an adequate model for such properties and combining kinematic quantities with dynamic ones allow us to make an attempt of solving adequately formulated equations of fluid motion.

4. Summary and conclusions

The active forces between the working surface and the dough piece surface cause the forming of the dough piece and adequate reactions of the piece material. These reactions (a response of the piece material showing the rheological properties of dough) are associated with the presence of shear and normal stresses in the piece material. These stresses are caused, on the one hand, by an external interaction and, on the other hand, by rheological properties of the dough (elasticity, plasticity, viscosity), represented by the so called structural (apparent) viscosity used in the relationships describing the relations between the deformation velocity and shear stress.

For the formation to take place, there should be one condition fulfilled, namely, the condition of dominance of external forces over the reaction forces of piece material.

The knowledge of the conditions for reactions of kinematic and dynamic quantities enables us to apply the above – presented analysis to the construction of adequate machinery.

1. The analysis of kinematic influences occurring during the formation of a cylindrical dough piece, carried out in this paper, is satisfactory for engineering practice and enables one to determine basic kinematic parameters of machines forming cylinder-like shapes. The presented description of the kinematic quantities together with the rheological properties make it possible to describe more precisely and determine relevant kinematic and dynamic forming quantities.
2. The proposed description for the course of the forming operation allows to formulate the kinematic relationships in accordance with the principles contained in both descriptions (spherical and cylindrical), and couple the presented kinematic quantities and interpret the course of the forming process.
3. The determined kinematic quantities and the preliminary description of active forces for the model description of cylindrical forming, allow us to define the loads of the forming system and to determine the necessary power to effectively form dough pieces.

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Model kinematyki formowania walcowego kęsów ciasta

S t r e s z c z e n i e

W opracowaniu przedstawiono opis mechaniki formowania kęsów ciasta w kształtki walcowe (walcopodobne). W oparciu o konfigurację formowania dokonano opisu ruchu formowanego kęsa oraz jego odkształceń powierzchniowych. Sformułowano zależności kinematyczne dotyczące materiału kęsa jako płynu reologicznego. Następnie określono związki sprzęgające wielkości kinematyczne występujące w obu opisach. Składowe tensora prędkości deformacji, przedstawione w przyjętej konfiguracji formowania (walcowy układ współrzędnych), opisują rozkład prędkości na powierzchni formowanego i deformowanego kęsa ciasta. Wyznaczone wielkości kinematyczne oraz określone powiązania między nimi mogą być wykorzystane do opisu procesu formowania kęsów ciasta w kształtki walcowe.