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MODELLING OF PROCESS OF PRESSING THE DOUGH IN DIE WITH SCREW INSERT

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Abstract: *It is proposed to install special screw-shaped inserts in the die for the production of pasta. The inserts has has injection-type screws shape. This allows to regulate the process of pressing the dough, pre-compacting the dough, plasticizing it and simultaneously heating it.*

A smooth transition of the dough in the forming holes is ensured, the hydraulic resistance of the forming channels is reduced, the quality of pasta improves, the productivity of the press increases and the durability of the die operation is increased.

A mathematical model of a pumping-type auger has been built, which makes it possible to obtain the same dough compaction coefficient for all screw channel inserts. The mathematical model of the screw sweep more accurately takes into account the shape of the helical groove in the normal section –a shape close to a trapezoid, and not to a parabolic segment.

The use of special inserts in the die improves the quality of semi-finished products, increases the productivity of the screw press by 20%, and reduces the specific energy consumption.

Keywords: *pasta, dough, die, auger, seal.*

INTRODUCTION

Pasta dies work well, but there are design flaws:

– significant hydraulic resistance in the bores of the die when the dough flow enters the forming holes;

– neven speed of pressing out the dough on the peripheral areas of the working surface of the die body.

Bores in matrices are deep and empty. The cross-section of the bores is larger than the total area of the forming holes. This results in a hydraulic shock when the dough flow enters the forming holes. In the bores, there is practically no preliminary compaction and plasticization of the dough, there is no preliminary preparation of the dough for the molding process.

This problem can be solved by installing special screw-shaped inserts in the die bores.

Analysis of modern technical solutions shows that for the bores of the die, the insert is best suited, made as a pumping-type screw, the width of the screw rates of which decreases in the course of the dough movement. This allows you to gradually and evenly compact the dough, additionally plasticize and heat it (Torgan A.B., 2015).

EXPOSITION

An injection-type spiral was adopted as the main sample of the insert shape. The insert is tightly installed inside the bore, in front of the forming holes with the formation of a gap of height h2. In Fig. 1 it is shows the installation diagram of the insert inside the die bore. The insert 1 is made as a pump-type screw and is installed in the bore 2 in front of the forming holes 3 with a gap 4 of height h2. The forming holes 3 have a diameter d0 and are located in the lower part of the die body 5. It is pressed into the lower part of the bore 2. The arrows show the direction of movement of the feedstock.

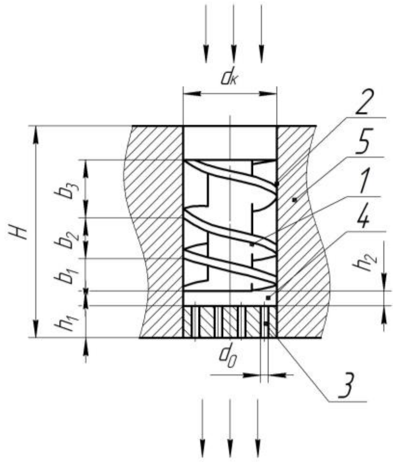

Fig. 1 Scheme of a screw-shaped insert into a pasta die:
1 – insert; 2 – well; 3 – forming holes; 4 – gap; 5 – die body; d^k – bore diameter; n_0 – the number of forming holes; h_1 – the height of the insert; H – the total thickness (height) of the die body;
l_1, l_2 and l_3 – the width of the screw grooves of the insert, with $l_3 > l_2 > l_1$.

Getting into the bore 2, the dough is preliminarily and gradually compacted with stationary spiral-shaped inserts 1 and fits through the gap 4 to the forming holes 3, which are already partially pressed and heated, which prevents the "hydraulic shock" and thereby partially reduces the resistance of the forming holes (by reducing the dough viscosity). The number of screw grooves depends on the depth of the bore and can be from 3 to 5. The height of the gap 4 can be as h2 = h1/2.

For normal and efficient operation of the device, it is necessary that the total area of the forming holes of the insert be equal to the normal cross-sectional area of the last turn of the screw, i.e.

$$\sum n_{о} d_{о} = F_{ш}, \tag{1}$$

where n_0 – the number of forming holes; d_0 – the diameter of the forming hole; F – the area of the normal cross-section of the last turn of the screw.

Rheological bases of pressing. A mathematical model.

High local pressures in the contact zone of the test particles with each other and with the working surface of the screw channel, the excess of the internal friction forces in the test flow over the external friction forces in extrusion processes lead to a complex of rheological effects that cause (Barsukov V.G., Sviridenok A.I. 1998; Fabrode, M.O., Callaghan J.R., 1989):

– Cork-like movement of the dough in the screw channel of the insert;
– Frictional heating of the dough due to energy dissipation on the working surfaces;
– Cork-like movement of dough in profiling channels with a transition from one rheological state to another;
– The occurrence of a tensile stress region near the exit from the extrusion channel.

All these rheological phenomena occur with the participation of friction forces and are called triboheological phenomena [2]. Due to the complexity of the analysis, these phenomena have practically not been studied, although they have a great influence on the modes of pressing the dough and the properties of the obtained semi-finished products. And here it is important that the douhg flow in the screw channels of the insert is compacted gradually and evenly, i.e. the compaction coefficient of the dough in each helical groove would have a constant value.

Mathematical model of the screw

The degree of compaction of raw materials is characterized by the compaction coefficient, which is the ratio of the volumes of turn-to-turn spaces at the locations of the first and last turns, while the pitch of the turns decreases towards unloading [5].

Due to a gradual decrease in the pitch of the auger turns, the product is gradually compacted, however, as the analysis of the design features of the auger shows, in practice there is an uneven (abrupt) compaction of the raw material, which negatively affects the quality of the finished product. This is due to the fact that the geometrical dimensions of the screw grooves are not interconnected with each other, and for this reason, the screw design needs significant improvement. In fig. 2 it is shown a diagram of a new type of screw (screw-shaped insert).

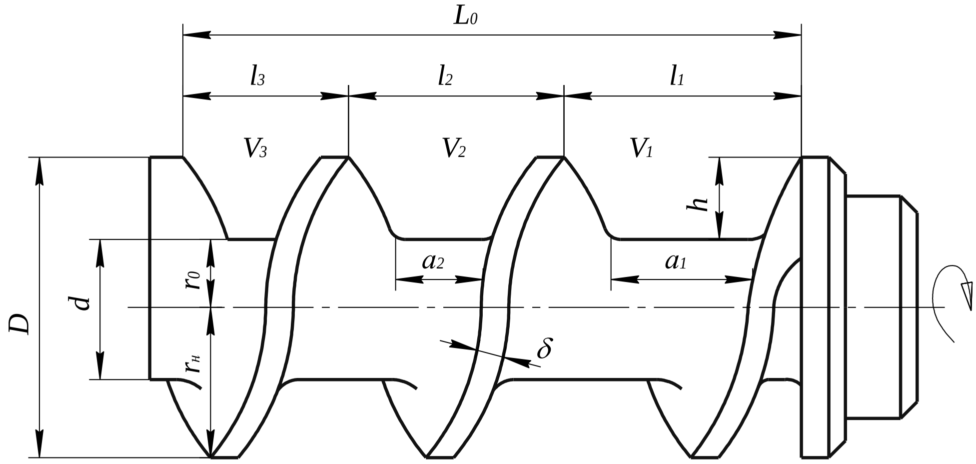

Fig. 2 Pumping type screw:
L_0 – the length of the working part of the screw; l_1 – the width of the first screw groove of the screw along its outer diameter; l_2 - the width of the second screw groove of the screw on its outer diameter; l_3 – the width of the third helical groove of the screw along its outer diameter; h – the depth of the helical groove; V_1, V_2, V_3 - volume, respectively, of the first, second and third inter-turn space; δ – the thickness of the screw thread; D – the diameter of the screw shaft; r_o – the inner radius of the screw; $R_н$ - the outer radius of the screw; d – the outer diameter of the screw; a_1, a_2 - the width of the helical grooves along the inner diameter of the screw

To construct a mathematical model of the screw, we use the laws of the theory of preferred numbers (Grudanov V.Y., 2005).

The width l_1 of the first screw groove of the screw along its outer diameter D is determined by the formula:

$$l_1 = 0{,}416 \cdot L_o, \quad (2)$$

where 0.416 is the proportionality coefficient; Lo - the length of the working part of the screw, m.

The width l2 of the second helical groove of the screw along its outer diameter D is determined by the equation:

$$l_2 = \frac{l_1}{1{,}272}, \quad (3)$$

where 1.272 is the proportionality coefficient.

The width l3 of the third screw groove of the screw along its outer diameter D is determined by the formula:

$$l_3 = \frac{l_1}{(1{,}272)^2} = \frac{l_1}{1{,}618} \quad (4)$$

where 1.618 is the proportionality coefficient.

Formulas (2–4) can be combined by the following equation:

$$l_n = \frac{l_1}{(1{,}272)^{n-1}} \quad (5)$$

Coefficients of ratios 0.416, 1.217 and 1.618 – preferred numbers.

Due to the gradual decrease in the step (width) of the turns (l1> l2> l3) of the screw, the product moves along the body, gradually and evenly compacted and approaches the forming holes in the form of a solid dense mass.

The last turn of the screw with the smallest pitch L1, pressing on the product, pushes it into the forming holes.

However, the quality of pressing and the efficiency of the machine largely depend on the degree and uniformity of compaction and compression of the product along its movement along the longitudinal axis of the screw.

A feature of the screw is that it creates a pressure sufficient for the product to pass through the forming holes. The degree of compaction of the product is determined by the coefficient of compaction (compression) K. The coefficient of compaction of the product is understood as the ratio of the volumes of inter-turn spaces at the locations of the first, second and third turns (or the first and last).

In the case of using formula (5), we obtain uniform compaction of the product, since $K_{1.2} = K_{2.3}$, and high-quality pressing of raw materials.

Experimental study

It is better to make the insert from the same material as the pasta die itself, bronze Br-AZh9-4, brass LS59-1, stainless steel 1X18N9T. It is desirable to polish or chrome the inner surfaces of the insert, but the best coating is teflon (fluoroplastic). The wall thickness of the insert should be minimal, but ensure the rigidity and strength of the structure (≈ 1.0-1.5 mm).

For experimental confirmation of the obtained model, special inserts were made, installed in the bores of the die for the production of noodles for a small pasta press (Fig. 3).

Fig. 3 Experimental prototype of a screw-shaped insert

Inserts were installed in the bores of the die. The output flow of pasta (semi-finished products) was measured in two cases:

I - the resulting mass without installed special inserts;

II - the resulting mass with installed special inserts;

In fig. 4 sit is shown a diagram of the experimental stand. The stand is based on a press equipped with instrumentation.

The tests were carried out under the following conditions:

– Ambient temperature - 21 ± 1 °C;
– Relative air humidity 72 ± 5%;
– Atmospheric pressure 750–760 mm Hg

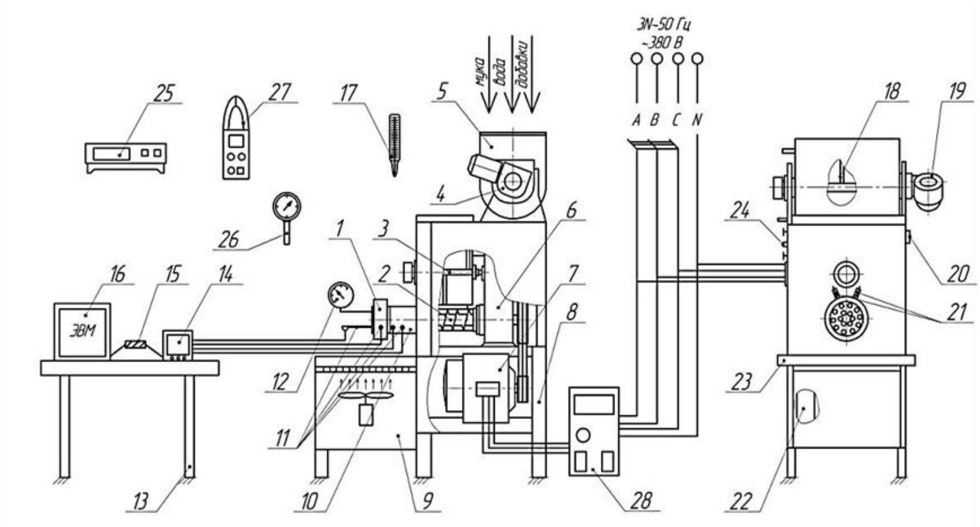

Fig. 4 Scheme of the experimental instalation:
1 – pasta die; 2 – auger; 3 – feed shaft with blades; 4 – worm gear; 5 – mixing hopper; 6 – gearbox; 7 – pressing body drive; 8 – frame; 9 – blowing unit; 10 – extruder body; 11 – thermoelectric converters; 12 – pressure sensor; 10, 13 – table; 14 – microprocessor-based measuring regulator; 15 – interface converter; 16 – personal computer; 17 – thermometer; 18 – stirring shaft of the mixing device; 19 – mixer drive; 20 – travel switch; 21 – cooling jacket fitting; 22 – electrical equipment block; 23 – tray; 24 – control panel; 25 – electronic scales; 26 – tachometer; 27 – electrical meter wattmeter; 28 – frequency converter

EXPERIMENT RESULTS

According to the results of the experiment, the length of the noodles increased by 20% with a noticeable improvement in quality (Fig. 5).

Consequently, the operation of the press with screw-shaped inserts increases the productivity of the equipment. Specific energy consumption is reduced.

The established productivity of the pasta press with a die with installed special inserts increases by 20%, and the productivity of the pasta press is directly related to the speed of extrusion.

a b

Fig. 5 Samples of obtained pasta
(a – using special inserts; b – without the inserts)

CONCLUSION

The use of a screw-shaped insert allows:

– to carry out a smooth transition of the dough into the forming holes without swirling the dough and its reverse feeding;

– to carry out additional compaction, plasticization and heating of the dough and to reduce the hydraulic resistance when pressing the dough through the forming holes;

– improve the quality of pasta;

– increase the durability of the forming holes.

It should be noted that in the presence of inserts in the bores of the die, it is possible to adjust the rate of extrusion of pasta in the radial direction of the working surface, changing the cross section of the last turn of the insert screw.

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