Calculation of the main parameters of the press extruder

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Abstract. In this work the issues of extrusion of leguminous crops are considered, information on modeling of process processes of press-extruders is given, analysis of the modern market of press-extruders is carried out and patent search of existing inventions in the field of extradited production is performed. A press extruder for processing leguminous crops has been developed and detailed information about the developed press extruder is presented. The ratio of the extruder power to the number of revolutions per minute was calculated.

1. Introduction
One of the main factors of rapid growth and health of farm animals is their nutrition. Progress in animal husbandry also depends on progress in the production of high-protein feed using environmentally friendly technologies.

Cost-effectiveness of production processes is the key to a successful economy. The use of special preparation of raw materials for further processing in specialized machines allows not only to achieve high quality of the final product. It also allows you to spend less energy and resources on production. Press extruders, which are designed on the basis of energy-intensive technologies that take into account not only the physical and mechanical, but also the rheological properties of high-protein feed, are very well suited for these purposes.

It is also worth noting that the efficiency of press extruders for the preparation of high-protein feed directly depends on their competent design.

2. Materials and methods
Description of the extrusion process. Extrusion is a common and effective method of heat treatment of feed components, the main task of which is deep gelatinization of starch, while the starch macromolecules are decomposed to form various dextrins and sugars, because of which the digestibility of feed is significantly increased, and the assimilation of nutrients occurs with less energy costs.

Extrusion is ideal for producing high-protein feed, as the process increases the nutritional value of the processed material by an order of magnitude. In addition, extrusion makes it possible to use by-products of feed production, which increases the yield of finished products and contributes to more resource-intensive agricultural production. The extrudate is almost completely decontaminated and meets the strict environmental requirements typical of modern feed production.

The design of the press extruders for the preparation of high-protein feed (table 1) determines the technological process. At the moment, the use of press extruders almost completely negates the negative factors that occur during the heat treatment of feed: the dry extrusion process takes less than 30 seconds,
while the raw material is sterilized and decontaminated (pathogens, fungi, mold are completely destroyed); increases in volume, increases the digestibility of feed. It is homogenized (the processes of grinding and mixing of raw materials in the extruder barrel continue, the product becomes completely homogeneous); it is stabilized (the action of enzymes that cause the product to burn out, such as lipase and lipoxygenase, is neutralized, anti-nutrients are inactivated.

**Table 1.** Technical characteristics of extruders.

| Full name | Capacity, kg/h |
|-----------|----------------|
| **ETR extruders (LLC "Stimul", Kirov)** | |
| Co brand | |
| ETR | Up to 100 |
| ETR | Up to 200 |
| ETR | Up to 350 |
| Etrs | Up to 500 |
| Etrs | Up to 600 |
| ETR 700/55 Turbo | Up to 800 |
| KFSO brand | |
| ETR | Up to 150 |
| ETR | Up to 300 |
| Etrs | Up to 400 |
| Etrs | Up to 500 |
| ETR 700/55 Turbo | Up to 700 |
| **PE series extruders (JSC "Zhasco", Volgograd)** | |
| 1100, 1100U, 1100S | |
| 900, 900U, 900S | |
| 750, 750U, 750S | |
| 370U | |
| 300U | |

Modeling of technological processes of press extruders.

A diagram describes a mathematical model of extruders for the preparation of high-protein feed (figure 1). The Diagram provides a visual representation of the dynamic state of the system, and what is especially important – it does not affect the differentiation of the internal time characteristic of the system.

![Figure 1.](image)

**Figure 1.** Structure of the mathematical model of the feed preparation process using a press extruder.
Modeling of the processes of press extruders for the preparation of high-protein feed is possible using the pressing scheme, which is shown in figure 2.

The basis of process modeling is the structure-forming approach, which characterizes the system of interaction between external and internal factors. This makes it possible to find optimal values for the effect parameters that demonstrate a symbiosis of output results.

Scientific studies of the working process of technical means for the preparation of high-protein feed, conducted by A. A. Artyushin, I. Z. Barfakov, V. G. Gopka, B. I. Vagin, G. M. Kukta, L. M. Kutsyn, S. M. Dotsenko, V. Yu. Frolov, A. V. Burmaga and others, have become decisive in the development and improvement of existing feed preparation equipment. The lack of universal equipment for the preparation of feed in the conditions of medium and small livestock farms was noted.

Modern market of press extruders.

**Figure 2.** pressing Scheme for the extruder.

**Figure 3.** KMZ-2U Press extruder.

**Figure 4.** Press-extruder of ETR «Stimul». 
Figure 5. Zhasco PE-110 Press extruder.

Designed for the production of high-performance extruded feed from grain and straw. Universal feed extruders ETR of the KFSO brand are designed for the production of prebiotic feed from grain, grain mixture, including rye, with the possibility of adding 30-50% hay, straw, oats, bran, husk, meat and bone meal, cake and meal. Complete with extruders of the KFSO brand is an annular die, a strand separator, a hopper with a stirrer. By changing the geometry of the augers and the auger part itself: productivity increases by up to 50%; energy is saved by about 25-30%; the screw part itself works longer; the spare parts for the extruder are cheaper.

Designed for the preparation of complete feed: from grain crops (wheat, barley, corn, etc.); of the various mixtures of grains, including from a mixture of grains and straw (reeds); waste from the processing of meat, poultry and fish in mixture with vegetable filling; from the humid stale grains, having the smell of ammonia. The PE-100 extruder is equipped with: a screw feed of raw materials with a frequency controller; a magnetic catcher; a one-piece centered shaft; vibration supports.

Technical characteristics: capacity 80-130 kg / h; installed power 11.37 kW; extrusion process temperature 115-170 °C; overall dimensions 850x850x1500 mm; weight 250 kg.

Figure 6. press extruder of ENCE GmbH: a – press extruder, b-diagram of the press extruder device.
The working part of machines of this type includes a set of screws, between which retaining washers are sequentially located. Augers and washers are fixed on the stud by means of a bolt having a conical head. On the inner surface of the casing of the working part, longitudinal channels are made so that the raw material does not rotate as it moves. At the outlet, the casing is equipped with a cone nut with a hole. Manipulation of the gap between the cones of the bolt and nut at the outlet, or the diameter of the outlet hole, allows you to adjust the temperature of the processed material.

In the food industry, extruders equipped with full-gearing screws that perform rotational movements in one direction are widely used. In such a design, the tops of one auger go into the depressions of the other.

Twin-screw self-cleaning extrusion machines are characterized by faster start-up of the screw and work at increased speeds. In such units, the pressure rises less often, because the product does not accumulate. In single-screw units, because material can accumulate in the coils, pressure rises occur more often. The result is an uneven output of products from the extruder.

The extruder is widely used for processing soybeans, barley, peas, wheat, corn, as well as for various mixtures of legumes and cereals. The principle of operation of the extruder consists in squeezing the processed product into special spinners arranged in the extruder barrel, while the processed mixture is subjected to high temperature (100-150 degrees) and high pressure (over 50 atmospheres).

Because of the extrusion process, the grain, due to the large pressure drop at the outlet of the extruder, increases many times in volume and increases the energy value of the product.

Technical characteristics: productivity, with a feedstock density of 0.65 kg / l is 250-400 kg / h; installed power 55 kW; extrusion process temperature 110-135 °C; overall dimensions 1630x1500x1500 mm; weight 1065 kg; specific energy consumption per 1 kg of product 0.085-0.22 kW.

3. Discussions and results
Let's turn to the patent search for press extruder designs. A device for treatment of feed containing the boot is equipped with a hollow housing in which is the auger having a stepped shaft and set it on helical coils with different inner diameter, is wound around the respective level of the shaft and the coil ends facing unloading the neck, mounted on a shaft with the possibility of reciprocating it in the axial direction (and.with. No. 1123626, A23N 17/00, 1981).

The disadvantages of the existing device are the high-energy intensity of the process, the heterogeneity of particles in the material composition of the resulting compound feed.

The essence of the invention is explained by drawings, where: in figure 7 General view of the press extruder is shown, in figure 8 fragment of the inner side of the housing on which the longitudinal ribs are located is shown.

![Figure 7. General view.](image-url)
The press extruder works as follows. When the feed hopper (figure 8) is filled with the initial grain mixture, the press extruder drive is switched on (not shown in the drawings). When the screw 3 rotates, the mixture is captured by its turns and moves from the feed zone 7 to the plasticization zone 8 and then to the outlet of the matrix 4. As the mixture moves in the press extruder housing, due to the friction forces caused by the decreasing winding pitch of the screw 3 and the diameter of the housing 1, pressure is created in the extrudate, the longitudinal ribs 5 with holes 6 additionally deform the processed material. As a result, the finished product exits through the cone-shaped openings 9, and the squeezed liquid flows freely along the groove 10 into the receiver in the form of a niche 11, and then through the outlet 12 is removed from the housing cavity. The pressure value is regulated by changing the size of the outlet opening of the cone nozzle 4.

Cone-shaped press-extruder, the technical result of which depends on the strength and reliability of the screw installed in the cavity of the housing, made with longitudinal ribs on the inside and having areas for feeding and plasticizing the grain mixture. The screw is made with a decreasing diameter in the direction of its rotation. When working at the location points of the ribs made in the form of paired diamond-shaped elements, a torque occurs on the screw shaft:

Total torque:

$$\sum_{i=1}^{u} T_i$$

(1)

The shaft is calculated for strength:

$$\sum_{i=1}^{u} T_i = W_p [\tau]$$

(2)

where $W_p$ is the polar moment of resistance.

For a solid shaft:

$$W_p = \frac{\pi d^3}{16}$$

(3)

$$d = \sqrt{\frac{16 \sum T_i}{\pi [\tau]}}$$

(4)

For a hollow shaft, where $d = DD \frac{d}{D}$:

$$D = \sqrt{\frac{16 \sum T_i}{\pi [\tau](hd)}}$$

(5)

$$T_i = F_i R_i$$

(6)
where $R_i$ is the distance of the rib relative to the shaft axis $F_i$ – Circumferential force.

It is often necessary to determine the shaft diameter from the power $N$ and the number of revolutions per minute $n$.

$$
\tau_{max} = \frac{\sum T_{max}}{W_p} \leq [\tau]
$$

Where $\sum T_{max} = 7162 \frac{N}{n} \text{Nm}$, if $N$ in KW:

$$
\sum T_{max} = 9550 \frac{N}{n} \text{Nm};
$$

$$
\frac{\pi d^3}{16} [\tau] = \sum T_{max} = 7162 \frac{N}{n};
$$

$$
d = \frac{3}{\sqrt{\pi [\tau]}} \frac{7162 \times 16 \times T_{max}}{n} = \frac{3}{\sqrt{[\tau]}} \frac{36000}{n} \frac{3}{\sqrt{N}}
$$

It follows from the formula that for a given power $N$, an increase in the number of revolutions $n$ leads to a decrease in the shaft diameter.

Taking $[\tau] = 20.0 \text{ MPa}$ (reference data), we get the value:

$$
d = 12 \sqrt{\frac{N}{n}}
$$

To reduce the deflection, we take instead of the specified $[\tau] = 20.0 \text{ MPa}$ $[\tau] = 12.0 \text{ MPa}$, therefore:

$$
d = 14.4 \sqrt{\frac{N}{n}}
$$

This formula is used in practice.

In addition, in order to avoid shaft vibrations, it is required that the twist angle does not exceed $1^\circ/4$ per 1 linear meter.

In this case, the calculation is based on the permissible deformation:

$$
\varphi^* = \frac{180^\circ}{\pi} \frac{T_{max} \times 100}{GY_p} = 1^\circ/4
$$

Substituting the values $Y_p = \frac{\pi d^4}{32}$, Tmax $T_{max} = 7162 \frac{N}{n}$ and $G = 8 \times 10^4 \text{ MPa}$, we get:

$$
d = 12 \sqrt{\frac{N}{n}}
$$

It is necessary to calculate the shaft so that it meets the strength condition and the torsional stiffness condition. In order to meet the strength condition for the shaft, it is necessary to calculate using the formula $d = 14.4 \sqrt{\frac{N}{n}}$, and according to the condition of permissible deformation, the value $d = 12 \sqrt{\frac{N}{n}}$ is required.

We can find the value of $\frac{N}{n}$ at which both conditions are met:
\[ 14.4 \left( \frac{N}{n} \right)^{\frac{1}{3}} = 12 \left( \frac{N}{n} \right)^{\frac{1}{3}} \]

Or

\[ \frac{12}{14.4} = \left( \frac{N}{n} \right)^{\frac{1}{12}} \]

Where from

\[ \frac{N}{n} \approx 0.11 \]

Thus, the ratio of the power \( N \) of the press extruder to the number of revolutions per minute \( n \) should be 0.11.

4. Conclusion

The conducted studies show, that the developed press extruder for processing leguminous crops is able to perform the required operations at a high level, and does not have the disadvantages found in similar press extruders. The calculation of one of the main parameters of the press extruder-the ratio of the press extruder power to the number of revolutions per minute – is made.

The state-of-the-art press extruder market, with significant growth over the past decade, is far from optimal. The feed extrusion process is currently a very promising technology for producing high-protein feed for farm animals. In addition, machine-building companies focus their attention on the development of press extruders for agricultural production.

Extrusion is the most advanced method of feed processing due to the environmental friendliness of the process and an increase in the concentration of useful substances and vitamins compared to the starting material.

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