The modelling of the crushing of meat raw materials for making management decisions in the production of emulsified meat products

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Abstract. The article describes an innovative approach of the grinding heterogeneous frozen meat raw materials on the basis of single-stage milling method. In the technological cycle, in comparison with the traditional solution, the one shredder is used instead of three meat-cutting machines. The high quality of the finished product is achieved by modeling the grinding parameters. As a result of the analysis of the experimental data of the “new” technological process of meat grinding, an intelligent control system for the production of minced meat with machine quality control is proposed. Promising technology will reduce the cost of production of mass demand products that meet quality standards.

1. Introduction
Currently, almost all Russian enterprises of the meat processing industry according to various estimates (85-95)% are equipped with imported equipment [1-3]. In this regard, it is necessary to solve the problem of import substitution of expensive meat processing equipment in the light of the requirements of the Doctrine of the food security of the Russian Federation. The analysis of quality of the meat products developed by domestic producers, showed, that not all products can be estimated positively, and it is required to improve qualitative characteristics of the meat products made in the Russian Federation, at strict observance of normative requirements to technology of their production. The creation of energy-and resource-saving technology for the production of meat products while reducing their cost and guaranteed quality on the automatic line, equipped with types of technological equipment of Russian production, will help to solve these problems. The theoretical aspects of the processing of frozen raw meat cutters are developed in V.M. Gorbatov Federal Research Center for Food Systems of Russian Academy of Sciences: the technique of analytical calculation of the performance of the cutting process meat cutter with helical teeth, the relative error not exceeding 6%; the calculation method of energy consumption for the cutting process of the raw materials by the method of milling on the basis of application specific cutting forces; the system of automatic process control of minced meat production with the use of the control computer is proposed, which provides a guaranteed high quality of the finished product [4, 5]. From the raw materials obtained at the current experimental installation of one-stage grinding of frozen meat by the method of milling, samples of finished products (cooked sausages, semi-finished products, canned food for kids) were developed, which surpass the similar products produced by traditional technology in terms of quality characteristics. Currently on the basis of the one-stage crushing of meat raw materials the automatic line on development of meat products of food with control system of quality of minced meat on the basis of artificial intelligence on the principle of “deserted technology” is created. As a result of a
significant reduction in the cost of finished products, energy saving and improving sanitary and hygienic indicators in its production, the meat products obtained by the proposed technology will be available to the mass buyer, including the poor.

2. Research tasks
The structural and mechanical properties are determined largely by the size of the particles of the crushed raw material, noted in [6-9], means, the degree of its grinding. It was proved [8-12], that with the help of structural and mechanical properties it is possible to control the technological parameters of raw materials and minced meat, the product quality at any stage of the technological process of minced meat preparation, as well as the consistency of finished products. It follows from this, that the machine control of the degree of grinding of the initial frozen meat raw materials largely determines the control of the entire technological process on the developed automatic line for the production of emulsified meat products. Taking this into account, it is possible to formulate the objectives of the management of a single-stage process of grinding frozen meat raw materials by milling method. Firstly, to maintain a given degree of grinding during heterogeneity of raw meat on the structural and texture characteristics. Secondly, to calculate the means of automatic control system (ACS) technological process forecast changes in the size of meat particles (meat chips) in the grinding process. In accordance with these objectives should solve the problem of synthesis of ACS. For this need: to choose the structure of the system, its elements and the topology of cause-and-effect relationships between them; to develop algorithms for control devices and the values of their parameters, for example, the settings of regulators [13]. During the cutting of frozen meat by cutters have a significant difference. The quality of grinding is significantly affected by the heterogeneity of frozen meat raw materials on the structural and texture characteristics. Different amounts of ice (water) in frozen meat at different storage temperatures; the presence of fat and connective tissue are structural signs of heterogeneity. Different orientation of the muscle fibers in the unit volume of the product relative to the blades of the cutter is a textural indication of the heterogeneity of raw materials. An approximate picture of the heterogeneity of the block of frozen meat on the structural and texture characteristics in the orientation of the cutting surface of the block relative to the cutter is shown in Fig. 1.

![Figure 1. Heterogeneity of frozen meat block.](image)

Trace of the cutting edge of the cutter with a screw tooth (Fig. 1) will pass through the fibers of muscle tissue, differently oriented with respect to it (longitudinal and transverse), through other types of tissues, volumes of ice of different shapes, sizes and orientations relative to the cutting edge. When placing the longitudinal beam of muscle fibers relative to the cutting blade of the cutter, the width of the cut layer of meat will be greater in comparison with the transverse arrangement of the same fibers. The impact of the above factors influencing the degree of grinding is random, so the statistical analysis of the size of the meat chips, chopped meat, and energy for cutting frozen meat raw materials of the multiblade tool.

3. Materials and methods of research
It was created the experimental set-IBF-1 (chopper units milling modification 1) for study the one-step process of cutting a block of frozen meat cutters. The design of the IBF-1 is schematically shown in Fig. 2.
The device of the chopper IBF-1 (figure)

1 - frame; 2 – guide chute; 3 – feed mechanism; 4 – cutting mechanism; 5 – casing; 6 – prefabricated container; 7 – cover; 8 – control cabinet (not shown in the figure).

The installation was completed with cutters of different design and geometry. The parameters of the cutting mode (the speed of the cutter and the feed rate in the grinding zone) were set by the corresponding settings of the frequency converters of the supply voltage working on the electric motors of the cutting mechanisms and the supply of the IBF-1 installation. The experimental blocks of frozen meat, cut from blocks of industrial size (bovine veneered second grade and pork veneered semifat), were ground at the plant. According to [14], the mass fraction of connective and adipose tissue in beef was no more than 20%, in pork the mass fraction of adipose tissue was in the range from 30% to 50%. The temperature of the meat in the center of the experimental block before grinding is -12° C-14° C. The placement of the experimental frozen meat block in the guide chute of the IBF-1 chopper is shown in Fig. 3.

The movement of the blocks to the mill was carried out by the impact on them of the rod of the chopper feed mechanism with a given feed rate on the guiding planes. The guiding planes of the working chamber IBF-1 were exposed and fixed in accordance with the size of the experimental blocks of frozen meat. The ground meat was extracted from the combined container and subjected to microstructural study. Microstructural studies were carried out in accordance with the current regulatory documentation [15]. Histological preparations were made on the freezing microtome MICROM HM 525. The sections were studied using a light microscope “Axio Imager.A1” (Carl Zeiss Germany) with the using of the computer program for image analysis.

The active power consumed by the electric drive of the cutting mechanism of the installation in the operating mode was measured and recorded by the industrial analyzer-registrar ASM-3192. Statistical analysis of the parameters of the grinding process (particle size of crushed meat – meat chips, and energy consumption for cutting frozen meat cutter) was carried out by calculating the numerical characteristics (mathematical expectation and dispersion) of the experimental distributions of these parameters obtained during the grinding of raw materials at the IBF-1. Verification of compliance of
the law of experimental distribution of parameters as random variables with the proposed hypothetical distribution law was carried out according to Pearson's consent criterion [16, 17].

4. Research results and discussion
The linear dimensions of the meat chips (thickness and width) of the crushed meat obtained at the IBF-1 unit grinding of the initial frozen raw material (beef) are shown in Fig. 4. The data are obtained as a result of microstructural analysis of the crushed raw material sample.

Figure 4. The size of the meat chips (beef) - chip thickness, mcm; - chip width, mcm.

The histogram of the density distribution of the frequency of ingress of the thickness of the meat chips, corresponding to Fig. 4, in the range of its values is shown in figure 5.

Figure 5. Histogram of the distribution of the frequency density \( f_i \) * ingress of the thickness of the meat chips in the range of its values (beef).

Solving the problem of equalizing the obtained statistical distribution, we hypothesized that the test (experimental) distribution corresponds to the normal law. The likelihood of this hypothesis was established by methods of mathematical statistics. Similarly, the experimental active power distribution was proved to be consistent (Fig. 6), consumed by the electric drive of the chopper cutting mechanism IBF-1 in operating mode, the law of normal distribution (Gauss).

Figure 6. Histogram of the power distribution frequency density consumed by the drive motor of the cutting mechanism of the IBF-1 installation in the operating mode, by the ranges of its measured values.
From the results of statistical analysis of the experimental distribution of active power consumed by the drive motor of the cutting mechanism of the IBF-1 installation in the grinding process, it follows that the average square deviation of the power is \( \approx 26\% \) of the value of the expectation estimate. In this regard, it can be concluded that the moment of resistance to grinding, that is, the load on the mill in the operating mode, varies significantly in magnitude. This is due to the significant heterogeneity of the feedstock, as noted above. When changing the load on the mill grinder in the operating mode, the frequency of its rotation changes, which leads to additional dispersion of the linear dimensions of the meat chips due to changes in the parameters of the cutting mode (the feed to the tooth of the cutter and the cutting speed of raw materials). This factor of influence on the degree of grinding of meat reduces the homogeneity of the produced minced meat, which leads to a decrease in the quality of meat products. Taking this into account, it is necessary to ensure the stabilization of the parameters of the cutting mode by means of the automatic control system of the grinding process in the operating mode of the grinder. The application of automatic control of one-stage technological process of minced meat production is shown by the example of the developed line for the production of emulsified meat products (Fig. 7).

**Figure 7.** Automatic sausage production line  
1 - input control equipment of raw materials; 2 – conveyor; 3 – milling shredder; 4 – storage hopper dispenser; 5 – minced meat; 6 – truck; 7, 8 – lifts; 9 – filling machine (syringe); 10 – device analysis of the chemical composition of the crushed meat; 11 – control computer (CC).  
During the implementation of this project, the task was not only to improve the technological process of cutting frozen meat raw materials through the use of a new method of grinding by milling, but also to ensure the production of minced meat of a given quality on the automatic line. For solving this problem the line was equipped with storage bins-dispensers, in which the required amount of crushed raw materials of each type was measured in accordance with the recipe of the finished product. The line is also equipped with equipment for monitoring the chemical composition of crushed meat (protein, fat, moisture) in the real time stream. In the process of mixing the minced meat in the minced meat mixer, the viscosity is controlled by a sensor and the pH of the minced meat is measured, water and other components provided by the recipe are dosed. These measurements are fed into an industrial computer that controls the technological process of producing emulsified meat products on an automatic line. For the synthesis of ACS technological process on the proposed line, in particular the problem of modeling the size of the meat chips in the grinding process, it is necessary to take into account the impact on the mill from the load. The above data give reason to assume in the first approximation the normal law of load distribution on the mill when grinding blocks of raw materials of industrial sizes. The analysis of experimental data allows us to assume a random process of loading on the mill stationary process, which has the property of ergodicity. This means that any implementation of a stationary random process of a certain duration sufficiently fully represents the entire set of realities of the process under consideration. Taking into account the results of experimental research, for mathematical modeling of one-stage process of grinding frozen meat raw
materials in order to predict the size of the resulting meat chips, it is advisable to use the method of forming filter (FF) [17] to simulate the perturbation acting on the system from the load (Mc in Fig. 8).

**Figure 8.** To the synthesis of ACS

OC – the object of control; FC – frequency converter that changes the speed of the cutter; AD – asynchronous motor drive mechanism of cutting the grinder; N(t) – white noise; U(t) – input signal (setting the cutting speed of raw materials); FF – forming filter; PC – speed controller (frequency) of rotation of the cutter; n – the speed of the cutter.

Control of one-stage grinding provides for the maintenance in automatic mode of the established degree of grinding of raw materials with the stabilization of the parameters of the cutting mode in real time. ACS technological process on the developed automatic line for the production of emulsified meat products has the signs of an intelligent control system [19]:

1) the presence of close information interaction of the intelligent system with the environment when using information communication channels - in case of control of one-stage grinding of meat blocks is controlled by their temperature, the presence of foreign matter, the weight of the blocks;

2) the existence of simulation predictions of changes in the external environment and their own behavior - in this case, the system simulates the size of the meat chips, obtained by cutting raw materials multiblade tool;

3) increasing intelligence and improving their own behavior - the system is trained in real time, specifying the forecast size of the meat chips in the process.

The algorithm of the ACS is characterized by the fact that, in addition to the statistical information obtained during the grinding of a real block of meat about the change in the speed of the cutting shaft under the influence of the moment of resistance to grinding, the industrial computer will have an additional amount of similar statistical information in the computer simulation of grinding "virtual" blocks of meat. This will calculate the point and interval estimates of the change in the frequency of rotation of the cutting shaft of the grinder in the grinding process, and on their basis, according to the established analytical dependence, to determine the same estimates for changing the characteristic size of the resulting meat chips with a given statistical accuracy and reliability. Besides, dispersions of the estimates themselves are necessarily calculated, that is, determines the degree of "blurring" of the boundaries of the range in which the size of the meat chips is located, which is important in the production of emulsified meat products. In the process of real grinding of block meat in the industrial computer accumulates a database and knowledge about the process and parameters of grinding, that is, the system is trained in the operating mode, improving its work on predicting the degree of grinding of raw materials. As a result of the implementation of the above algorithm, the control system will have statistical information about the degree of grinding of raw materials in digital form. The structure of the ACS may include equipment for rapid analysis of the chemical composition of the crushed meat, as well as its temperature after grinding. Then the further process of minced meat production can be controlled strictly in the function of time, excluding the subjective factor of assessing the degree of readiness of the final product. This will allow you to get the finished product of a given high quality.
5. Conclusion

Thus, an innovative approach to obtaining minced meat of a given quality, while strictly controlling the degree of grinding and readiness of the final product. The organization of the quality control system of minced meat on the equipment does not require complex technical solutions, and is achieved by using software with simulation of grinding parameters. At the same time, the control system operates in the mode of interaction with the external environment, is self-learning in the process of work and predicts the influence of external factors on the process of grinding meat raw materials.

6. References

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