Use of artificial intelligence in the production of high quality minced meat

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Abstract. A design for an automatic line for minced meat production according to new production technology based on an innovative meat milling method is proposed. This method allows the necessary degree of raw material comminution at the stage of raw material preparation to be obtained, which leads to production intensification due to the traditional meat mass comminution equipment being unnecessary. To ensure consistent quality of the product obtained, the use of on-line automatic control of the technological process for minced meat production is envisaged. This system has been developed using artificial intelligence methods and technologies. The system is trainable during the operation process, adapts to changes in processed raw material characteristics and to external impacts that affect the system operation, and manufactures meat shavings with minimal dispersion of the typical particle size. The control system includes equipment for express analysis of the chemical composition of the minced meat and its temperature after comminution. In this case, the minced meat production process can be controlled strictly as a function of time, which excludes subjective factors for assessing the degree of finished product readiness. This will allow finished meat products with consistent, targeted high quality to be produced.

1. Introduction

Modern trends in the development of meat processing equipment include the use of highly precise methods for meat raw material analysis and high-calibre control of raw meat processing [1]. According to expert estimates, large manufacturers of sausages and meat products in the Russian Federation (RF) will trend towards quality stabilisation and maximal automation of technological processes.

At present, according to different estimates, virtually all Russian meat processors utilise 85-95% imported equipment. In this connection, it is necessary to solve the problem of substituting this expensive, imported meat processing equipment in the light of the requirements of the Food Security Doctrine of the Russian Federation.

Earlier, the V.M. Gorbatov All-Russian Meat Research Institute developed the theoretical aspects for frozen meat raw material processing by a novel milling method: methodology was developed for analytical calculation of performance of the meat cutting process using a mill; a method was proposed for calculating energy expenditure for the meat raw material milling process based on the specific shear force established experimentally; an automatic control system was proposed for the minced meat
The 21st century is imposing new requirements on meat and meat product manufacture. To increase enterprise profitability, novel, innovative approaches to the organisation of raw material processing into finished products will be necessary, including mechanisation, robotisation and automation of production. Many manufacturers of food equipment are gradually beginning to develop universal lines for production of certain product types, where raw material is supplied at the entry; with that, processing, transportation and mixing with other ingredients are carried out in automatic mode. At the exit, a finished product or raw material suitable for the following technological processing stages is obtained [3].

The Executive Order of the RF President No. 642 of 01.12.2016 “On the Scientific and Technological Development Strategy of the Russian Federation” states that in the next 10 to 15 years, a transition to advanced intellectual production technologies, effective processing of agricultural produce, and the development of safe and quality food products including functional foods must be considered the priorities for the scientific and technological development of the RF [4]. Therefore, the development of a system for on-line automatic control of the technological process for minced meat production using artificial intelligence methods and technologies is quite topical.

2. Automatic line design
At present, the Institute has been developing an automatic line for minced meat production intended for the manufacture of semi-prepared products and sausages, including products for children’s nutrition. The line design is presented in figure 1.

![Figure 1. Design of the automatic line for minced meat production: 1 – input control unit for processed raw material; 2, 4, 6 – conveyers; 3 – milling cutter; 5 – hopper for minced raw material; 7 – minced meat mixer; 8 – elevator with a buggy; 9 – stuffer; 10 – process control computer (PCC).](image-url)

Frozen meat blocks are moved from freezing chambers to the input control unit 1), where unconditioned raw material that contains foreign material inclusions (metallic items, wood, glass, fragments of packaging materials etc.) are identified and rejected. Meat blocks that pass this test are transferred by the conveyer (2) into the milling cutter (3). Minced raw material is carried by the conveyer (4) into the hopper (5), from which it is sent in measured weight quantities by the conveyer (6) to the minced meat mixer (7). After mixing, the formulated mass is transferred into the buggy and
loaded by the elevator (8) into the stuffer (9). Then, sausages are subjected to thermal treatment according to a standard technological scheme. The process of minced meat processing is controlled by the PCC (10) that monitors, in real-time, the raw material temperature, the comminution process, the chemical composition (content of water, protein and fat; pH) and the temperature of the minced meat, forming a command for mixing (producing) minced meat with optimal rheological characteristics. When manufacturing a meat mass for homogenised canned foods for children’s nutrition, the automatic line is additionally furnished with a heat exchange apparatus and homogeniser instead of a stuffer.

3. Single stage comminution
The proposed design utilises a new technology for meat product manufacture based on an innovative method of raw material comminution. The traditional technology for sausage production involves consecutive comminution of frozen meat blocks using three meat cutting machines: block cutters (comminution to medium-sized particles), grinders (coarse comminution to small-sized particles) and cutters (fine comminution). In the proposed technology, only one machine, a single stage comminutor, finely comminutes the initial raw material. This has the following advantages: 1) costs of minced meat and sausage production are significantly reduced due to exclusion of two expensive meat cutting machines for preliminary raw material comminution (the frozen meat cutter and grinder are unnecessary); 2) each stage of the preliminary comminution using traditional technology is characterised by electricity consumption and meat losses; with the new technology, these losses and consumption are excluded; 3) a reduction in the length of the chain for minced meat production leads to intensification of minced meat/sausage production, making the novel technology more cost effective. To obtain the necessary particle size when producing homogenised canned foods for children’s nutrition, the meat mass for these canned foods is traditionally processed in a colloidal mill or micro-cutter or using a dual system of disintegrators after meat raw material is comminuted in a grinder and then is transferred to a homogeniser. Using the novel, single stage comminutor results in a product with the necessary degree of comminution of the meat mass for these canned foods. Therefore, the proposed design, utilising the new technology, would be suitable for use in the children’s nutrition industry with all the advantages described above for sausage production.

The single stage meat comminutor is furnished with a cutting element in the form of a rotating body (screw) with cutting edges on its flanges [5]. The screw can be made from a set of mills in materials approved for contact with the food environment. When cutting raw material with mills, the contact area of the cutting edges with meat is minimal compared to the area of the side surfaces of cutter knives (the traditional technology of fine comminution); therefore, it is possible to ensure a reduction in the energy expenditure due to friction. By processing meat blocks of typical industrial sizes by the novel milling method in a single stage, the traditional technological chain of meat block processing (frozen meat block cutter – grinder – cutter) is reduced to a minimum, which ensures resource savings. This technological chain reduction leads to a significant (by 2.4 times when the automatic line performance is 2000 kg/hour) decrease in electricity usage, which allows meat processing plants to save financial resources.

4. Intelligent control system (ICS)
In the traditional technology for minced meat production, using batch-operated technological units, finished product quality, to a large extent, depends on the operator. The new technology, realised on the proposed automatic line, envisages complete automation of the technological process with the use of the PCC; that is, control is conducted according to the principle of an unmanned operation based on artificial intelligence. This will allow finished products of guaranteed high quality to be obtained by computer control both of each technological operation and the whole technological process in real-time.
To this end, on the proposed line, the creation of an intelligent control system (ICS) for quality management of minced meat production is planned, the distinctive characteristics of which will be: 1) function in a mode for information interaction with the external environment via sensing elements that measure parameter values to follow the process; 2) the system will be trainable in the process of operation: it accumulates and uses statistical information to increase the precision of predicting the degree of raw material comminution; 3) the system will produce predictions of environment effects, assessing numerical characteristics of such effects.

Control of single stage comminution envisages maintenance of the stipulated degree of raw material comminution in the automatic mode upon stabilisation of the cutting mode parameters in real-time.

In this case, the ICS will operate under the principle of compensating for parameter deviation from a set value (figure 2).

The PCC calculates the moment of the meat’s resistance to comminution by the dynamics of the cutting driver of the comminutor upon fixing the values of the electromagnetic moment of the electric motor of the driver of the cutting mechanism. As a result of this calculation, the PCC memory unit archives the realisation of a random process – the changes in the moment of meat resistance to comminution over time – in the form of a data array. Based on the statistical data obtained, the PCC assesses the correlation function of the process and calculates an estimate of the spectral density of the process by the standard method based on the discrete Fourier transformation. This assumes that a change in the moment of resistance to comminution is a stationary process (in a broad sense, a random process) that has an ergodic property upon stabilisation of the parameters of the raw material cutting regime. The PCC uses the obtained estimate of the spectral density of this random process in a Monte-Carlo statistical computation. Increasing the length of the process realisation in the mode of machine (i.e. modelling) time means the PCC obtains a larger volume of statistical information about the process and, consequently, about changes in the rotational speed of the comminutor cutting shaft on which this process depends. Thus, in addition to the statistical information (obtained when cutting a real meat block) regarding changes in the rotational speed of the cutting shaft under the influence of the moment of resistance to comminution, the PCC will have an additional volume of similar statistical information due to computer modelling of changes in “virtual” meat blocks. This will allow the PCC to calculate point and interval estimates for process changes in the rotational speed of the comminutor cutting shaft during the process of comminution. On the basis of these estimates, the PCC will make the same estimates for changes in the typical size of the meat shavings obtained, with targeted statistical accuracy and reliability using established analytical dependence. The PCC will also

**Figure 2.** Control of single stage meat block comminution: 1 – electric motor for the driver of the cutting mechanism for raw material; 2, 4 – frequency convertors; 3 – PCC; 5 – electric motor for the driver for the mechanism feeding meat blocks into the comminution zone; 6 – spiral gear; 7 – frozen meat block; 8 – screw (comminutor cutting body).
calculate the dispersion of these estimates; that is, it will determine a “diffusion” degree for a boundary range of meat shaving sizes, which is important in manufacturing products for children’s nutrition. In the process of real comminution of meat blocks, the PCC accumulates and processes statistical information about the comminution process; that is, the PCC is trained in the work regime, improving its prediction of the degree of raw material comminution. As a result of the presented operative algorithm, the PCC will produce statistical information about the degree of comminution in an explicit (numerical) form. The PCC can include equipment for express analysis of the chemical composition of comminuted meat as well as its temperature after comminution. In this case, the following process for minced meat production can be controlled strictly as a function of time, thereby excluding subjective factors in the assessment of finished product readiness.

5. Conclusion

The proposed technology for meat raw material comminution and the designed automatic production line will result in finished minced meat/sausage products with consistent, targeted high quality. Complete automation of the technological process of minced meat production using the ICS opens the door to designing automatic plants – the meat processing plants of the future.

References

[1] Maksimov D A and Zakharov A N 2013 Trends in the development of meat processing equipment All About Meat 3 10-2

[2] Lisitsyn A B, Ivashov V I, Zakharov A N, Kapovsky B R and Kozhevnikova O E 2013 Intelligent quality control system for minced meat All About Meat 6 32-8

[3] Plyasheshnik P I, Kapovsky B R, Glebochev S N and Shikhov S S 2016 Automated lines in the meat sector Meat Industry 1 32-4

[4] Kapovsky B R, Pchelkina V A, Plyasheshnik P I, Lazarev A A and Dydykin A S 2017 Methods of incoming control of meat blocks on the technological lines Meat Industry 5 28-31

[5] Lisitsyn A B, Semenova A A, Kapovsky B R, Kuznetsova T G and Zakharov A N 2017 An innovative method of fine comminution of meat raw material. An alternative to a long-standing tradition Fleischwirtschaft International 2 60-5