Specificities of control over multifactorial objects in food production

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Abstract. The research deals with control methods of multifactorial objects of food production, representing diverse technological processes occurring in continuous, discrete-continuous and discrete modes. This is especially relevant for systems in food production having the series connection of technological units, separated by apparatus-technological capacities and resistances. For such units, a transient delay value is significantly greater than that of single-capacity objects. A solution proposed: the use of two-loop automatic control systems capable of improving system quality parameters in facilities of chemical and technological processes. The two-loop automatic control system is relevant when the object is subjected to frequent disturbing influences from the regulator and has a low inertia parameter. The internal control loop suppresses arising internal disturbance caused by the specifics of the process itself, and the external loop is responsive to disturbing influences coming from outside, e.g., with changing properties of the incoming raw materials.

1. Introduction

Food production as a complex system for control represents different categories of processes occurring in discrete, continuous, and discrete-continuous modes. For example, serial connection of separate devices with differing quality parameters of raw materials, depending on the process of preparation of a biotechnological product, leads to the appearance of abrupt perturbation representing one of the most severe disturbances in the control system. It should also be noted that the series connection of technological units separated by technological capacities and resistances generates a capacitive or transient type of delay, which, together with the “net” (transport) delay, significantly exceeds the delay value in single-capacity objects.

When selecting the control system structure for the technological complex (TC) in food production, it is necessary to consider specificity of technological and equipment organization of TC which is dependent on such aspects as normalized processing time of certain types of food raw materials, its variable properties and composition, requirements for quality parameters of the finished product [1]. At the same time, modern highly efficient TC bear an increased risk of significant losses due to possible rework of the defect products.

A single-loop control system used in modern TCs, manufacturing food, is not always able to provide the required quality parameters of the finished product.

Selection of the multi-loop control system for multi-factor food production TC is preferred, taking into account the equipment and technological combination of processes that perform a full cycle of...
operations affecting the quality indicators of the finished product [2]. Increasing quality indicators in the transient regulation process, in this case, is provided by the reduction of the control system delay time and increased levels of regulatory effects when connecting control channels affecting the output parameters of the object [3].

2. Research methods

Figure 1 is a structural-parametric diagram of the TC producing butter, comprising of external and internal factors [4]. The external factors include cream which is the raw material for production of butter. Cream undergoes preliminary technological preparation operations, potentially providing an impact on the process of butter churning and its moisture content. Internal factors include technological operations of the transfer of incoming cream into butter with a given level of moisture content [5]. One of the main sources of disturbances is the cream coming in the butter-churning machine. This is due to the fact that at the stage of cream ripening, technological factors affecting the final moisture content in butter – a ripening temperature of the cream and a fat content in the cream – are usually uncontrollable. When the next cream-ripening tank is connected, their values may differ since these disturbances of a stepped nature.

![Figure 1. Structural scheme of butter manufacturing in butter churning machine of continuous operation](image)

Factors, affecting moisture content of the final product at the stage of churning, are supplied cream temperature, agitation speed of churning and supply of a normalizing component. The control of these factors is achieved by using relevant equipment. The use of various combinations of control factors can be applied to provide synchronization of modes in the manufacturing process.

To determine the level of influence of the technological factor on 1.0% change of the moisture content, the coefficient of humidity formation (transition factor) is used. The transition factor is calculated according to the formula:

\[ K_h = \frac{\Delta W}{\Delta S} \]  

where \( K_h \) – coefficient of humidity formation, % humidity / factor measuring units; 
\( \Delta W \) - change in the moisture content in butter, %;
\( \Delta S \) - change of the factor, factor-measuring units.

### 3. Research results

The results of analysis of technological factors influence on 1.0% change in the moisture content in butter within technological limits are given in table 1.

Analysis of technological factors in the production of butter determines the cumulative effect of uncontrollable factors as a disturbance. At the same time, the simultaneous deviation of the fat content in the cream and the cream ripening temperature within the technically permitted range may lead to an output deviation in moisture content as high as ± 4.0%. This situation is characterized by the transient mode butter churner work associated with the connection of another reservoir and caused by occurrence of disturbances of stepwise nature, which greatly complicates the stabilization of the moisture content of the finished product [7].

As the results of the analysis, in this case, the total control action of three factors – supplied cream temperature entering the churning, agitator rotational speed and supply of the normalizing component, potentially can be used to stabilize the butter humidity, since the level of their total influence exceeds the impact of uncontrollable factors

| Factors forming humidity parameter | Technologically allowed range of variation of the factor | Possible deviation in butter humidity, % | Coefficient of moisture formation (transition factor), \( K_c \) |
|------------------------------------|--------------------------------------------------------|------------------------------------------|-------------------------------------------------------------|
| External                           | Fat content in the cream, %                            | 38 - 45                                  | 5.6                                                         | 0.8                                                         |
|                                   | Cream ripening temperature, °C                         | 4 - 7                                    | 2.6                                                         | 0.9                                                         |
|                                   | Supplied cream temperature, °C                         | 8 - 14                                   | 15.0                                                       | 2.5                                                         |
| Internal                           | Agitation speed of butter churn, s\(^{-1}\)            | 17.4 - 30.0                              | 13.6                                                       | 1.0                                                         |
|                                   | Supply of normalizing component, %                     | 0 - 2                                    | 2.0                                                         | 1.0                                                         |

The proposed solution allows us to quickly compensate the deviation of moisture in the finished product caused by the disturbing influence in operational and transient operation modes of butter churn.

Analysis of equipment and technological solutions allows justifying the choice of controlled and uncontrolled process factors and setting the level of their influence on the formation of moisture of the finished product, as well as the type and nature of the disturbances at the stages of cream ripening and butter production. Considering the complexity of the process of formation of butter humidity, presence of intermittent external disturbances and delay of the equipment-technological system "cream-ripening reservoir – butter churn", we proposed a structure of multi-channel control, including realization of control actions depending on the current value of the moisture content of output butter with computing potentially expected humidity deviation of the finished product. The structure of the multi-channel control of the butter production process is represented in Figure 2.

In the operational control mode, when connecting the next reservoir to the churn, cream flows through the heat exchanger which stabilizes the predetermined temperature level before cream enters the churn. Thus, an allowable temperature drop of 3-4 °C inside the churn is additionally provided. For the mentioned two modes of operation, two separate independent control loops for temperature control of cream are used, respectively.
In this structure of the multi-loop control system, the control actions are realized through equipment and technological channels of the butter production process. In the operational mode of butter churning, deviations in the temperature of supplied cream in the heat exchanger before entering the churn avoided because of the decreased time delay achieved by preliminary computation of expected disturbance. To increase the transition factor, the cumulative effect of the equipment and technological channels of systems interconnected with the moisture content of butter is used.

In case of uncontrolled intermittent disturbances, when connecting the reservoir with the deviation in the content of fat in cream or in ripening temperature, the cumulative effect of parallel-sequential introduction of control actions is used. In such case increased influence of the control action from the agitation of churning on stabilization of moisture content replaces control action from normalizing the component channel. Such a method of making control actions, considering the complex shape of the perturbation, provides rapid stabilization of the moisture content in butter in the final stage of production.

4. Conclusion
A structural basis of this multi-loop control scheme is a microprocessor providing formation of operations stabilizing the moisture content of butter produced in the multifactor equipment-technological complex. An adopted structural scheme in a process of performing operations stabilizing the moisture content of butter provides operating mode of control channels within technologically and hardware-recommended limits. Economic efficiency of the considered technical solutions is proved in [9].

![Diagram of multi-loop control system](image_url)
References

[1] Tikhomirova N A 2011 Technology of milk and dairy products. Butter technology (technological notebooks) (SPb.: GIORD)

[2] Brusilovsky L P and Weinberg A Ya 1993 Automated process control system for whole milk and milk-canning productions: handbook (Moscow: Kolos)

[3] Blagoveshchenskaya M M and Zlobin L A 2005 Information technology of process control systems (Moscow: "Higher School")

[4] Stegalichev Yu G, Balyubash V A and Zamarashkina V N 2006 Technological processes of food production. Textbook for high schools (Rostov / D-Spb.: Phoenix)

[5] Grishchenko A D 1983 Butter (Moscow: Light and food industry)

[6] Vyshemirsky F A and Ivanova N V 2005 Cow's milk butter: standardization and terminology Cheese making and butter making 1 2-24

[7] Balyubash V A and Alyoshichev S E 2007 Formation of a multi-channel system for stabilizing the humidity of butter Cheese making and butter making 2 45–46

[8] Ivanov V L, Polyakov R I and Travina E A 2019 Problems and economic efficiency of automation of product quality control at food industry enterprises Economics: yesterday, today, tomorrow 9 (1A) 121-134