System Analysis of the Technological Processes Stability

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Abstract: A fundamental property of the technological process is - Stability. The information obtained as a result of the statistical analysis of accuracy and stability of the technological process can be used as an argument for a regulator in the automatic-control system to synthesize the corresponding control action. The stability of the technological process as a probabilistic characteristic reflecting the quality of its course has been used for a long time and all this indicator was determined in different ways. The article provides an overview of the various approaches of various authors to the definition of stability. In addition, the paper analyzes the advantages and disadvantages of such approaches, as well as proposes a method based on the ratio of the process dispersions over the sliding time intervals. The importance of introducing the function of managing the stability of a technological system is difficult to overestimate, since the widespread introduction of the quality control system of Hazard Analysis and Critical Control Points (HACCP) does not allow considering the possibility of managing the quality of technological processes over time, but only statically, which does not guarantee the production of quality products.

Keywords: Stability of the technological process, statistical analysis, automation, systems of automatic control.

1. Introduction

Industry development at all stages of its formation always set up a number of requirements, first of all to qualitative characteristics of produced products, and with introduction of automatic-control systems, directly to the production process. The basis of the quality management process is the highest perfection of production, its technology and organization, which is characterized by the ability to consistently manufacture products in strict accordance with the requirements of regulatory documents. At the same time, achieving of the competitive level of the product quality dictates the need for a wide application of modern methods, techniques and tools of quality management, implementing the forward-looking strategy and ideology of the quality control.

To properties of any process one can attribute the following:

- Certainty, i.e. the extent to which the actual process conforms with its original description;
- Cost, i.e. the total cost of performing the functions of the process and the transfer of intermediate results between them;
- Replication, i.e. the ability of the process to create the output streams with the same characteristics, approaching the specified characteristics during repeated implementations;
- Manageability, i.e. the degree of process control in order to carry out pre-assigned tasks;
- Efficiency – extent of optimality in use of resources for achieving the necessary results;

A fundamental property of the technological process is a more complex analogue of the replication property, namely, the stability of the technological process. The information obtained as a result of the statistical analysis of accuracy and stability of the technological process can be used as an argument for a regulator in the automatic-control system to synthesize the corresponding control action. In this case, the delay in the channel of the management system is a fundamental factor of effectiveness and feasibility of using the performance stability of the technological process.

Statistical analysis of accuracy and stability of the technological process is the establishment by statistical methods of values of accuracy and stability parameters of the process and

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identification of patterns of its occurrence in time [3]. Methods of statistical analysis and evaluation of products quality during the manufacturing process, and statistical process control techniques are components of the products quality control.

The purposes of the statistical analysis methods application of accuracy and stability of the technological processes and quality of the product at the stages of development, manufacturing and consumption of products are, in particular, the following [15]:

- determination of the actual performance characteristics of accuracy and stability of the technological process, equipment or product quality;
- determination that the quality of products corresponds to requirements of the standards specifications and the technical documentation;
- verification of compliance with the technical discipline;
- study of random and systematic factors that can cause appearance of defects;
- identification of production and technology reserves;
- substantiation of technical standards and tolerances for the products;
- evaluation of the results of prototypes testing before justification of requirements and specifications for the product;
- substantiation of selection of technological equipment, as well as measuring apparatuses and tests;
- comparison of various product samples;
- substantiation of replacement the continuous control by the statistical one;
- revealing of possibility to implement the statistical management methods for quality control of the products.

There are several definitions of the "stability" term in relation to the process. For example, according to the State Standards of GOST RV 15.002-2003 SRPP VT «Quality management systems. General requirements» [19] and GOST 15895-77 «Statistical methods of products quality control. Terms and definitions» [20], stability, in relation to technological processes is a property of the technological process that causes a constancy of the probability distribution of its parameters during a certain time interval without interfering from outside. In relation to systems, stability is the ability of the system to function without changing its own structure, and to be in balance and should be invariable in time. As quantitative indicators of the accuracy and stability of the technological process, various criteria were offered. At the same time, it is obvious that in any case the process will be accurate, if the controllable parameter distribution does not overstep the norm frames, and it will be stable, if the same does not occur during a definite interval of time.

To ensure the stability of the statistical control of the process, checklists are commonly used as a component, first introduced by Shewhart in 1924 [17].

Timely detection of instability, to what, in turn, the use of the Shewhart control charts was focused, can help to prevent the appearence of defects. Considering independence of an average and root-mean-square deviation in the case of the normal distribution, control charts are usually used in pairs, for example for average and standard deviations. The purpose of application of the Shewhart control charts is the revealing of output points of the process from the stable state for the subsequent determination of reasons for deviations and their elimination [6], [1].

Technological processes of the food manufactures are realized, as a rule, in the form of technological complexes including the interconnected various apparatuses and equipment, co-operating streams of raw materials, energy, components, semi-finished products and final products. They are characterized by a high level of the information incompleteness on properties of initial raw materials about the raw materials properties directly during the technological process.

Starting from the above stated, the parameter of the technological process stability should possess the following properties:

- Efficiency is time of obtainibg the information by the system about the process stability. (The information about assessing the stability of the process as the main way to assess the conformity of the products to initial requirements should reach the appropriate regulator of the automatic control with the minimum delay. Due to production capacity in the modern industry, the time lag in the control channel is one of the main criteria for the effectiveness of the automatic control);
- Informativity is the conformity of the stability parameter to actual properties of the process. (The criterion for the informative value of the stability of the process is the unification of the information in the index of the stability of the process and its accuracy to originally specified requirements).

2. Accuracy and stability parameters

For estimation of the accuracy and stability parameters, various methods were offered. For example, during manufacturing of exact technical products, the following parameter of the process accuracy is applied [2]:

$$K_r = \frac{6S}{T}; \tag{1}$$

where S is the average quadratic deviation, T is the product tolerance

$$T = T_B - T_H; \tag{2}$$

Often, in manufacturing of precision engineering products, this parameter is sufficient in view of the fact that the disturbances on raw materials during this process are virtually absent. The disturbances that persist are associated only with fluctuations in voltage and frequency of the mains power supply, deterioration of working parts of the extruder, etc. Their amplitude and frequency changes are such that the problem of compensating of consequence of these disturbances is quite simple.

Gorbachev [10] offers a more general form of the Eq. (1):

$$K_r = \frac{\omega}{T}; \tag{3}$$

where the stray field $\omega = I(y)S;$ with $I(y)$ the factor depending on the law of distribution of the controllable parameter.

At the normal law of distribution of the controllable parameter and confidence level of y =0,997, $I(y)$= 6; The process is considered as accurate, if K_r <1. Thus, the stray field of the controllable parameter should be less than the tolerance zones on this parameter. If K_r > 1, the process is not accurate (in technological sense, there is a waste) and correcting acts on its regulating are necessary. Gorjachev [10], and also recommendations of the P 50-601-20-91 [2] suggest to estimate the stability as

$$K_C = \frac{S_{T1}}{S_{T2}}; \tag{4}$$

where S_{T1} is the average quadratic deviation during the fixed moment of time; S_{T2} is the average quadratic deviation during the compared fixed moment of time;

The process is considered as stable at $K_C \to 1$;

Khersonskiy and the Proshin [12] offered a method for estimation of the process stability using the Kohran criterion, which represents the criterion of the dispersions uniformity analysis at equal volume of selections:

$$G = \frac{S_{\max}}{\sum (S_i)}; \tag{5}$$

where $S_{\max}$ is the greatest from selective average quadratic deviations; S_i is the selective root-mean-square deviation for k selections. Thus

$$S = \sqrt{\frac{(\sum_{i=1}^{n} x_i - \bar{x})^2}{(n-1)}}; \tag{6}$$

where $\bar{x}$ is the dispersion centre (a selective average arithmetical); x_i is the result of i_{th} measurement; n is the sampling volume;

Value of the Kohran criterion Ga for a certain required significance value a is defined from tables [7]. Thus, if $G < Ga$, the process is considered as the stable one.

The index of dispersion is provided in regulatory documents STP EE0.019.058 [5], STP RUVI.019.067 [14] and STP RUVI.070.035 [4], which considers only dispersion of the process and characterizes its conformity to the tolerance zone width. In fact, it is inverse value of the accuracy parameter (3) and it is calculated as:

$$C_p = \frac{\Delta}{6\sigma}; \tag{7}$$

where Δ is the width of the tolerance zone, σ is the estimation of the root-mean-square deviation that is supposed to be counted Eq. (6)

From the technological point of view, the dispersion index > 1 is sufficient. The figures presented in reports of such leading car manufacturers, as Ford, Mercedes, GM, specify the experience of application by them C_p > 1,33. [9].

In electronic industry, by the Motorola Company instance, the dispersion index, or «the reproducibility index» is C_p > 2.0 that corresponds to production of defective units no more than 3.5 pieces per one million of products.

Also the regulatory documents STP EE0.019.058 [4], STP RUVI.019.067 [14] and STP RUVI.070.035 [4] provide index for the property of being centered. A recommendation on application of the centrality index is C_{pk} > 1.33 [9].

$$C_{pk} = \frac{d}{3\sigma}; \tag{8}$$

where d is the distance from the centre of the distribution curve to the proximal tolerance limit, σ is the estimation of the root-mean-square deviation that should be calculated Eq. (6)

In [16] a method for evaluation of the technological process is proposed using the variation coefficient of quality used in the food industry: raw protein, cellulose, salt, calcium, phosphorus, etc.

$$V_C = \frac{\sqrt{\frac{\sum_1^n (x_i - \bar{x})^2}{n-1}}}{\bar{x}}; \tag{9}$$

where x_i is the current value; $\bar{x}$ the average arithmetical value; n the number of experiments;

If <3%, the technological process for this indicator is considered as stable and accurate. If 3 % < V_C < 7,5 %, stability of the process is good [13]. If 7.5% < V_C <15%, the stability of the process is satisfactory. If V_C > 15%, the stability of the process is inadequate. It is indicated that the mean value of the analyzed values may differ significantly from the initial requirements specified for < 3%, then the process is stable, but inaccurate [13] It was also proposed a method of assessing the stability of the technological process using the entropy as a measure of relations ordering in the system:

$$\eta = 1 - \frac{H}{H_{\max}}; \tag{10}$$

where H is entropy of the system, which is in a given functional condition. $H_{\max}$ is the greatest possible entropy matching to the full uncertainty in behavior of the system, it is offered to accept it further as equal to 1.

At the above specified assumption Eq. (10) has a form:

$$\eta = 1 - \frac{H}{1}; \tag{11}$$

Entropy of the functioning system is calculated as [22]:

$$H = -P_1 \log_2 P_1 - P_2 \log_2 P_2; \tag{12}$$

where P_1 is the probability of the event occurrence in a desirable interval, $P_2 = 1 - P_1$ is probability of the event to go out of the specified interval.

Thus, for convenience of $-P\log_2 P$ calculation it is offered in [22] to use the corresponding table of ready values [14].

It is necessary to note that the listed above parameters, anyhow, characterize process from the point of view of stability, without comparing an average value of the process $\bar{x}$ with a preset value. For estimation the readiness of the technological process, the corresponding parameter is offered to calculate by the following formula [2]:

$$K_H = \frac{\bar{x} - x_\delta}{\delta}; \tag{13}$$

where $\bar{x}$ is the average arithmetical value; x_σ the middle of the tolerance zone, δ the tolerance zone. The process is considered as adjusted at $K_H \to 0$;

The factors observed above, based on the mathematical tools of the statistical analysis, consider separately either accuracy, or stability. Besides, in the case of the technological processes in the food industry, for obtaining data about processes, laboratory research is required that in the case of application even the infra-red express analyzers, all the same introduces the essential delay in the regulating channel, that in its turn is unacceptable for the functioning of the automatic-control systems.

Analysis of the above described methods to assess the stability and accuracy of the functioning of the technological systems indicates that they are based on the use of the mean-square deviation, the standard mean-square deviation of a random variable with respect to its mathematical expectation based on the unbiased estimation of its variance, the tolerance and entropy as a measure of the bonds ordering in the system.

Application of entropy for estimation of the process stability is inconvenient from our point of view, since it assumes knowledge of values of the event fulfillment probability in a desirable interval and probability of the event going out of the set interval. We can estimate the approximate values of the specified probabilities from the inequality of Chebyshev, from which follows that the probability of that the random quantity differs from its mathematical expectation more than by k standard deviations, is less than $1/k^2$, however it is only an approximate value. Application of the root-mean-square deviation and the standard root-mean-square deviation has its advantages, however, there are also deficiencies. Yehorov et al. [24] compared estimations of the random quantity dispersion according to which it is concluded that:

- Advantage of the dispersion comparing to the mean absolute deviation is that the integrand in Eq. (14) is differentiable at all points in the $(-\infty;+\infty)$ interval, and in terms of mean absolute deviation in the general case Eq. (15), it has no derivative at $x=a$;

$$D[X]=\int_{-\infty}^{+\infty}(x-a)^2\,dF(x); \tag{14}$$

$$\int_{-\infty}^{+\infty}|x-a|\,dF(x); \tag{15}$$

- The main advantage of the dispersion against the average absolute deviation that the dispersion is better than the average absolute deviation reacts to large deviations of a random quantity and weakly reacts to the small ones.
- Though $D[x]$ and $\sigma[x]$ have the same information on dispersion of a random quantity X, $\sigma[x]$ is more convenient, since its dimension coincides with the dimension of this random quantity.

Yehorov et al [24] underlined that as the dispersion of any parameter of the technological process as a system characterizes its ability to reach the assigned task: the given range of dispersion and the given range of the absolute value of the unknown quantity Xi, it is possible to evaluate the stability of the technological process by the degree of resumption of the dispersion in time τ by the following formula:

$$St=1-\frac{\left(\frac{\sigma_{Xi}}{\bar{x}_i}\right)_n-\left(\frac{\sigma_{Xi}}{\bar{x}_i}\right)_m}{\left(\frac{\sigma_{Xi}}{\bar{x}_i}\right)_n}; \tag{16}$$

where σ_{Xi} is the random quantity dispersion; $\bar{x}_i$ the mean value; n the designation of the moment of time of the estimation σ_{Xi}; m the designation of the $n+\Delta\tau$ moment of time.

Expression Eq. (16) as it is underlined by authors [24], is true in the case, if the structure of the technological process during the time τ between two measurements has not been changed. In this case the deviation in the dispersion estimation will be connected with the manifestation of the influence of disturbances both in terms of uniformity of characteristics of the raw materials used, and in terms of constant values of constructive and technological factors.

In the paper of the same authors [25] the simplified method of check stability of processes and systems is offered. The method is based on the method developed by Bartlett. It is applicable only in that case when all samplings have the same volume. At regular intervals, samples from the stream of the finished product are taken, from each test samples of equal volume n are taken, there has been made k such selections. It is offered for each sampling to find the corrected selective dispersion of the random quantity, i.e. the concentration of a key component. Obtaining k corrected selective dispersions $(s_1)^2, (s_2)^2, \ldots, (s_k)^2$, one computes the magnitude of the fraction Eq. (17):

$$G = \frac{s^2}{(s_1)^2 + (s_2)^2 + \ldots + (s_k)^2}; \qquad (17)$$

where s^2 is the maximum from all numbers $(s_1)^2, (s_2)^2, \ldots, (s_k)^2$.

In the monograph [18] there is the table VIII, from which one can find the value $G_{\max}$ for significance values of 5 % and 1 % corresponded to parameters *k* and *n -1*. If it will happen that $G > G_{\max}$, the hypothesis about equality of dispersions of the random quantities corresponded to tests, so about stability of a process, should be rejected (at the agreed significance level). If $G > G_{\max}$, there is no reason for rejecting the hypothesis. Thus, authors [25] suggest to evaluate efficiency of processes and systems on a parameter of the stability considering the maximum and minimum dispersions of the random quantity distribution x_i throughout an interval of time allowing to obtain authentic results of measurements. In [26] it is underlined that considering importance of monitoring of possible deviations of quality indicators of ready mixtures, it is offered to evaluate the stability of functioning of the technological processes by the following Eq. (18)

$$St = 1 - \frac{D[x_i]_{\max} - D[x_i]_{\min}}{D[x_i]_{\max}} = \frac{D[x_i]_{\min}}{D[x_i]_{\max}}; \qquad (18)$$

where $D[x_i]_{\max}$ and $D[x_i]_{\min}$ are maximum and minimum dispersions the random quantity x_i distribution as a parameter for estimation of the functioning stability of the technological system.

From the technical point of view, the criterion of the technological stability should be convenient for the solution of the monitoring problem of the processes inside of a certain unit, defining the resistance of the controllable object to perturbations that prevent its normal operation [23]. It is underlined that with forces $f(\dot{x}, x, t)$ and perturbations $R(\dot{x}, x, t)$ which affect it, it is possible to describe the question of stability of the analyzed technological installation by the following expression Eq. (19):

$$\ddot{x} = f(\dot{x}, x, t) + R(\dot{x}, x, t); \qquad (19)$$

In view of demands, the definition of the technological stability of the mechanical system is described by the following differential Eq. (20)

$$\dot{x} = f(x, t) + R(x, t); \qquad (20)$$

where x, f, R are vectors Eq. (21) in $\Re^n$ space:

$$x = \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ x_n \end{bmatrix} f = \begin{bmatrix} f_1 \\ f_2 \\ \cdots \\ f_n \end{bmatrix} R = \begin{bmatrix} R_1 \\ R_2 \\ \cdots \\ R_n \end{bmatrix}; \qquad (21)$$

where functions $f(t, x)$ and $R(t, x)$ are defined over the range included in $n+1$ dimensional space Eq. (22)

$$t \geq 0, (x_1, x_2, \ldots, x_n) \in G \subset E_n; \qquad (22)$$

where E_n is the linearly rationed n-dimensional space, and functions $R_i(t, x_1, x_2, ..., x_n)$ are perturbations acting permanently with the assumption Eq. (23):

$$\| R(t, x_1, x_2, ..., x_n) \| \leq \delta; \tag{23}$$

The method described in [23], is completely based on the nonlinear physics of phenomena of description of the technological process.

In [27] the method is described of the stability prediction of the TFEA (Time Finite Element Approach) flour-grinding process initially offered in [11]. The basic idea of TFEA is that the dynamic behavior of flour-grinding process is controlled, first of all, as a discrete linear card. The dynamic card can be described as:

$$\begin{Bmatrix} q \\ \dot{q} \end{Bmatrix}^n = A \begin{Bmatrix} q \\ \dot{q} \end{Bmatrix}^{n-1} + B; \tag{24}$$

where A is the matrix of the conditions measurement, dimension of which depends on number of the restricted in time elements and the polynomial order representing one period. B is the vector depending on process parameters. q and $\dot{q}$ are sets of x and y positions and speed. Stability of the flour-grinding process is defined by intrinsic values of the A matrix.

Sahal in his work [8] assumed that frequently emersion of effective solutions is the result of synthesis of two or more older solutions. By analyzing the methods of the stability estimation presented above and accuracy of the processes, we suggest simultaneous application of the Shewhart control cards and the combined stability parameter.

3. The offered stability assessment indicator

So, on the basis of operative with the minimum lag coefficient of the data channel about direct or indirect figures of merit of the product, control cards of Shewhart are constructed for each of the chosen parameters. The quality indexes should be chosen so that to make decisive impact on their quality and to provide for stability of the processes [21]. On the basis of the obtained cards the following analysis is performed:

- on the basis of offered in the State standard [21] criteria for checking structures on the special reasons we carry out the analysis of appearance of not casual reasons as the indication of presence of special reasons which should are analyzed and corrected by the automatic-control system;
- on the basis of the obtained data, we carry out the analysis of likelihood characteristics of the process, for their further application in calculation of the combined stability parameter Eq. (25) and its further consideration in the corresponding controller for synthesis of the control action in the system securing management of the technological process [13].

As the basis for estimation of stability we suggest to use the Eq. (18) for the stability parameters. It is necessary to understand that the practical application of the stability estimation Eq. (18) during the technological process is possible only during the sliding time interval. Suggested in [26] formula has its deficiencies, as follows:

- it does not consider the readiness of the process that leaves possibility of representing the process as the stable one during permanent "deterioration", i.e. smooth displacement from the center of the tolerance field of the process;
- the relationship between minimum and maximum dispersions of a random-process will be tended to 1 both at $D[x_i]_{\max} \to D[x_i]_{\min}$ and at $D[x_i]_{\min} \to D[x_i]_{\max}$. Under equal parameters of stability, the processes in that case will differ strongly from each other.

For solving the specified problem, it is suggested to introduce the combined parameter, taking as a basis the offered formula for the stability and multiplying it by the Euler number in the power with the reversed sign of the readiness parameter taken by the module Eq. (13):

$$St = \frac{D[x_i]_{\min}}{D[x_i]_{\max}} \cdot e^{\frac{-|(\bar{x}-x_\delta)|}{\Delta}} \cdot th\left(\frac{\Delta}{6\sigma}\right) \cdot \lambda; \quad (25)$$

where $D[x_i]_{\max}$ and $D[x_i]_{\min}$ are maximum and minimum dispersions of distribution of the random quantity x_i as a parameter of the estimation of the functioning technological system stability; $\bar{x}$ the average arithmetical value; $x\delta$ is the tolerance zone middle; Δ - the tolerance zone. Process is considered as stable one at $St \to 1$;

If the process is statistically operated, the control cards realize the method of continuous statistical monitoring of the zero hypothesis that process did not change and remains stable. But, since the value of a concrete deviation of the process characteristic from the purpose, which could draw attention, usually is impossible to define in advance, as well as the risk of the second order error, and the sampling volume does not calculated for satisfying the corresponding risk level, the Shewhart card can not be considered from the point of view of testing the hypotheses. Shewhart underlined empirical utility of the control cards for determination of deviations from the state of the statistical controllability, but not their probabilistic interpretation [17], [21].

4. General properties of stability as characteristics of the process

Here are some obvious statements describing the stability of a process as a concept:

1. Stability is a property of the process, incl. technological process;
2. The property of stability is a differentiated, not a binary property (that is, there is a “level” or “degree” of stability);
3. The means of achieving a "given" degree of process stability is control.

We distinguish 2 types of stability - Absolute stability (an idealized concept, is not achievable in nature) and conditional stability (quasistability). In practice, it is possible to use precisely quasistability. Quasi-stability (further simply “Stability”) is a property of the technological process that characterizes the constancy of ratios and causal relationships between its three multiplicative components:

a) stability of product quality indicators St_Δ;

b) stability of technical and economic process indicators St_E;

c) mass volume stability of process performance St_Ξ.

To determine the stability of the process at a qualitative level, like any other property of any other process, there are indicators of stability; Stability indicators are multiplicative components of stability itself. In this way: $St = St_\Delta \cdot St_\mathrm{E} \cdot St_\Xi \cdot \lambda;$ where λ - stability factor unaccounted component. With the decision not to take into account the specific component, we consider it equal to one.

Stability of product quality indicators St_Δ – the product of the "final" stability of the processes of change of specific indicators of product quality; For example, for extruding biopolymers, $St_\Delta = St_\sigma \cdot St_D \cdot St_C \cdot St_W \cdot ... \cdot St_N \cdot \lambda;$ where St_σ - stability of product’s surface heterogeneity changes; St_D - stability of the product’s diameter changes; St_C - product color stability; St_W - moisture stability; St_N - stability of changes in other indicators of product quality, such as protein content, degree of denaturation, etc. - St_{N+1}; Due to a longer time lag in obtaining quality assessments for the calculation of which laboratory research is required (St_W, St_N, St_{N+1}), when building an ACS, it is proposed to take the values of such indicators equal «1».

Stability of technical and economic indicators of the process St_{E} – the product of the "final" stability of the process of changing the degree of wear of equipment – St_{λ} and the process of changing the cost indicators of the components of the cost of production – St_{φ} (the cost of raw materials, the cost of energy, the cost of equipment maintenance, payroll, etc.); In this way: $St_{\text{E}} = St_{\lambda} \cdot St_{\varphi} \cdot \lambda$.

Mass-volume process performance stability St_{Ξ} – "Ultimate" stability.

Thus, the generalized structure of stability can be represented by an oriented tree (connected acyclic graph) with a root corresponding to the overall stability (Figure 1).

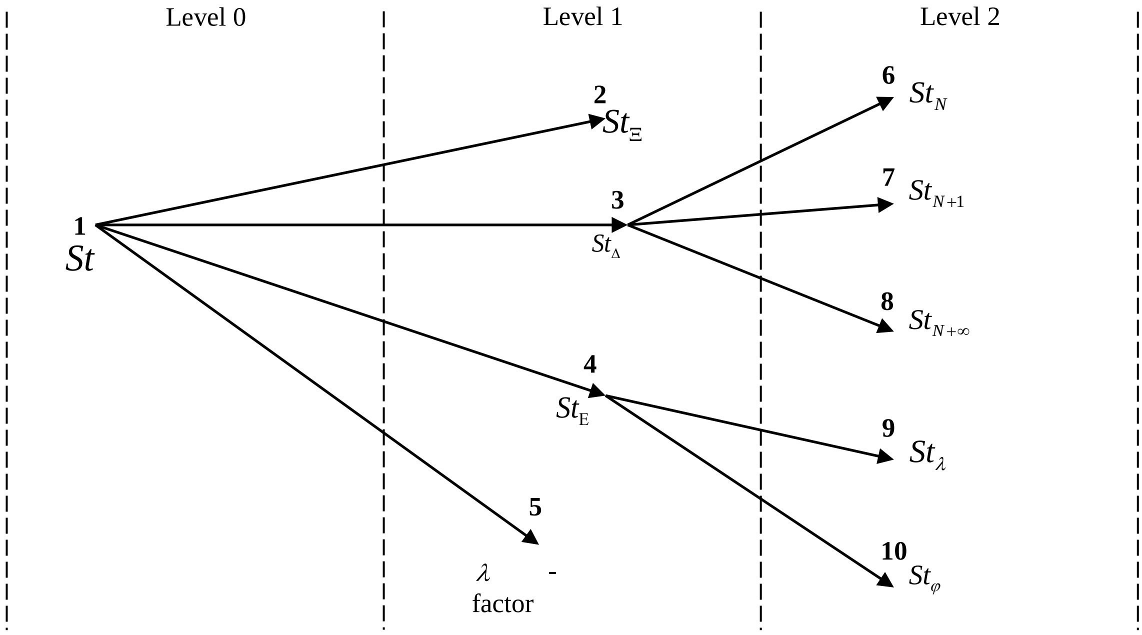

Figure 1. Representation of the generalized structure of stability using the graph

This graph is an ordered graph. The outgoing degrees of all vertices except the terminal (i.e., except the terminal nodes) are not less than 2. The terminal vertices (terminal nodes) of the graph shown above are the vertices: 2, 5, 6, 7, 8, 9, 10. Obviously, terminal vertices can be at any level except zero. The subsystems corresponding to the terminal vertices of the graph in the graph representation of the structure of generalized stability, considered as a complex system, are the elementary components of the system - the “final” stability. Imagine the general structure of the stability structure (Figure 2):

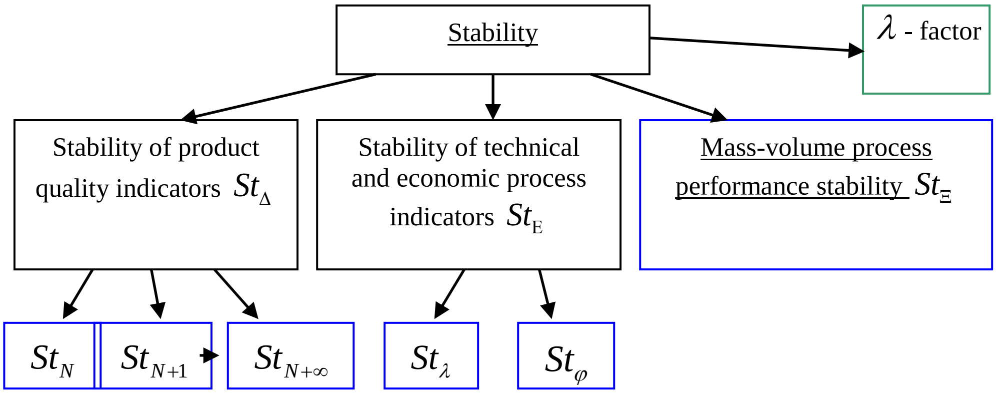

Figure 2. Overall stability

The final stability is a property of the indicator change process, which characterizes its ability to keep the values of this particular indicator within the specified tolerance limits for a certain time interval with a standard deviation → 0 and mathematical expectation → to the middle of the tolerance field.

However, all of these methods allow us to obtain a characteristic of not stability, but only one of its properties. Thus, for example, the proposed formula for calculating stability (1.1) gives an idea only about the stability of oscillations in the process, but does not characterize the mood of the process (matching the mathematical expectation of the process to the middle of the tolerance field) and does not characterize finding the probability distribution of the process within the tolerance fields.

In his 1981 paper [8], Devendra Sakhal (a professor at New York University) suggested that the emergence of effective solutions is often the result of a synthesis of two or more old ones. So, to solve this problem, I propose to introduce a combined indicator, taking the formula of the stability index of oscillations proposed in [24-26] and multiplying it by the components characterizing the mood and finding the distribution within the tolerance fields: (1.2):

$$St = \frac{D[x_i]_{\min}}{D[x_i]_{\max}} \cdot e^{\frac{-|(\bar{x}-x_\delta)|}{\Delta}} \cdot th\left(\frac{\Delta}{6\sigma}\right) \cdot \lambda; \qquad (1.2)$$

where $D[x_i]_{\max}$ and $D[x_i]_{\min}$ - maximum and minimum variances of the distribution of a random variable x_i ; $\bar{x}$ - arithmetic mean (expectation); $x\delta$ - middle margin; Δ - tolerance field; σ - standard deviation estimate; λ - stability factor unaccounted component.

With the tendency of all three multiplicative components of the formula to the unit, the index of ultimate stability is $St \to 1$ those. the process is tuned, characterized by stable oscillations and the probability distribution is within the tolerance field. The analysis of the components of the "ultimate" stability assessment formula is shown in (Figure 3):

$$St = \frac{D[x_i]_{\min}}{D[x_i]_{\max}} \cdot e^{\frac{-|(\bar{x}-x_\delta)|}{\Delta}} \cdot th\left(\frac{\Delta}{6\sigma}\right) \cdot \lambda;$$

Oscillation stability (stable at $\to 1$)

Mood (customized with mathematical expectation $\to$ mid tolerance)

The spread of the distribution (satisfies the function $\to 1$)

λ - factor

Figure 3. Analysis of the components of the evaluation formula "Ultimate" stability

1. $St = \frac{D[x_i]_{\min}}{D[x_i]_{\max}} \to 1$ asymptotic approximation to “1” with stabilization of the process oscillation level;
2. $e^{\frac{-|(\bar{x}-x_\delta)|}{\Delta}} \to 1$ with a mood ratio $K_H = \frac{\bar{x} - x_\delta}{\Delta} \to 0$;
3. The function of hyperbolic tangent $th\left(\frac{\Delta}{6\sigma}\right) \to 1$ with scatter index $C_p = \frac{\Delta}{6\sigma} \to \infty$.

5. Conclusions

The proposed indicator of stability is combined, with stabilization $St \to 1$ at destabilization $St \to 0$. Process stability is one of the key characteristics of any process, including and technological. The application of the assessment of the stability of the technological process significantly expands the capabilities of the automatic control system, which is important for increasing the efficiency of technological processes in the food and grain processing industries. One of the ways to achieve a given level of process stability is the use of guarantee management systems to prevent an event of an indicator of stability beyond the tolerance limits defined by the operator. In addition, the implementation in the automatic control system of the subsystems of guaranteeing control over the stability of quality indicators will make it possible to minimize the delays in the control channels due to the lack of previously unavoidable continuous laboratory studies.

The importance of introducing the function of managing the stability of a technological system is difficult to overestimate, since the widespread introduction of the quality control system of HACCP does not allow considering the possibility of managing the quality of technological processes over time, but only statically, which does not guarantee the production of quality products.

The multiplicative nature of the stability structure leads to one of the conclusions of the system analysis: destabilization of any of the components of the stability of the process leads to destabilization of the whole process. In this case, destabilization should be understood as the process by which one of the multiplicative components of stability decreases or its change leads to a decrease in any of the other two components of stability. The state of equilibrium is the state of the system, in which the indicator of the stability of the system is in one of the points of optimality.

The nature of relationships and causal relationships between the three multiplicative components of generalized stability presupposes the existence of a special nature of the mutual influence of its components on each other, described by a certain law, characteristic of each process separately. The study of such a special nature of the mutual influence of those who are of general stability on each other is the subject of further research.

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