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Technological Chain Modeling to Control the Quality of New Product Manufacturing

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Моделювання Технологічних Ланцюгів для Контролю Якості Виробів Нової Техніки

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***Abstract*—On the basis of the decomposition of the production technological processes optimization problem, the main tasks of their analysis and synthesis, which are solved at the main stages of their life cycles, were identified. A logical scheme of the system optimization as territorially distributed objects is proposed. As a detailed description of the logical scheme an information model of the technological chain is presented, which allows not only to reflect the process of finished products quality forming, but also to quantify the impact of each technological operation on its formation.**

***Анотація*—На основі декомпозиції проблеми оптимізації виробничих технологічних процесів виділено основні задачі аналізу та синтезу, що вирішуються на основних етапах їх життєвих циклів. Запропонована логічна схема системної оптимізації технологічних процесів як територіально розподілених об'єктів. Як деталізація логічної схеми наведена інформаційна модель технологічного ланцюга, яка дозволяє не тільки відобразити процес формування якості готової продукції, але й оцінити кількісно вплив кожної технологічної операції на її формування.**

Keywords—technological process, life cycle, system optimization, technological chain, information model.

Ключові слова—технологічний процес, життєвий цикл, системна оптимізація, технологічний ланцюг, інформаційна модель.

I. INTRODUCTION

The design processes, the development, the modernization and a re-engineering of the modern manufactures planning expect resolving the set of the interconnected tasks of the technological processes (TP) optimization, which are applied on them [1, 2]. Modern TP of the new equipment creation can combine a complex technological chains (TC) and separate technological operations, have complex relationship between the elements, characterizing by a considerable not stationarity. This significantly complicate the task of the getting their adequate mathematical descriptions.

The manufacturing TP optimization consists of the best variants choosing from the set with the admissible one, that satisfy functional and cost restrictions of the rates set (quality, product cost, system efficiency, the equipment loading, etc.) [3]. One of the first tasks here is the system optimization task of TP, that is resolving at the all main stages of their life cycles and provides compatible synthesis of the manufacture and administrative subsystems. The resolving problem of the TP optimization is done with the help of mathematical modelling, that provides their system representation with the further analysis of their structure, mathematical description development and the studied parameters assessment.

II. BACKGROUND

Generally, technological processes should be considered as territorially or spatially the dispersed objects (systems) $s = < E,R,G >$ (where E – the set of TP elements; R – the set of the relationships between the elements; G - TP topology, that determines territorial or spatial elements' distribution and relations between them) [4]. The TP optimization purpose is its efficiency maximization (extent of effect ratio from its functioning Q and the spent resources C). Effect from TP use is considered as not decreasing function from the resources spent for its achievement $\overline{Q} = F(\overline{C})$ (where $\overline{Q}$, $\overline{C}$ - the generalized scalar assessments of effect and expenses; F – an operator, that displays a resources use strategy, spent for TP).

Optimization models of TP and TC should establish relation between effect rates and charges and their structural, parametrical, topological characteristics. At the same time close task interrelation of a structural, functional, parametrical and topological synthesis, which require their unite resolving, creates the problem, for which resolving a development of the corresponding system methodology is needed [5–6]. In a context of the aggregation-decomposition approach, it could be considered as metatask, that consists of the set of tasks, which are belong to different hierarchical levels, with their interrelations according to input data and resolving results:

$$MetaTask = \{ Task^l \},\ Task^l = \{ Task_i^l \},\ l = \overline{1,n_l},\ i = \overline{1,n_i}\ , \quad (1)$$

where n_l – an amount of description levels, n_i – a task amount on level l. At the low level a task complex of the system optimization is resolving: a construction principles selection; a structure selection; a definition of the elements topology and relations; a functional optimization; a definition of the elements parameters and relations; an efficiency and a decision choosing assessment. One of the important task in the efficiency assessment process процесі and decision choosing according to quality TP is a task of the control and equipment quality assessment at all its stages (operations).

The main source of information, that opens an essence of TP and TC, are their mathematical models. The main purpose of these models considers the interrelation structure of disclosure between components of processes (chains) and the development of algorithms for their controlling. In the same time in modelling process the tasks of interoperational relationships analysis (technological chains modeling) and establishment of dependences between parameters of preparations inside the operation (technological operation modeling) are resolved. The greatest spread for resolving such tasks have got methods of the theory of correlation, experiments planning and information modeling. During information modeling method using, TC is given in a form of information channel, which information about the one preparation parameter is moving at який надходить інформація про один параметр заготівки. Gradually such channel is changing to the information about the prepared detail [7].

The carried-out review of the current state of the TP system optimization problem found out the contradiction, which specifies that existent technologies allow conditionally independent task resolving of their structural, topological and parametrical optimization, that doesn't allow to provide efficiency and heredity of decisions, which are accepted at the different stages of their life cycles. This means the urgency of the task of TP system optimization methodology development, that provides the right problem decomposition to the task complexes, which are belong to different description levels and their optimization stages, the development of the complex of the corresponding mathematic models, methods and technologies.

III. RESEARCH RESULTS

Technological chains modeling for quality control of the new equipment products performs together with the development of the other means of methodical, mathematical, information providing computer-aided engineering systems of TP [8–10]. From the information technologies point of view, each of these tasks represents itself the input data converter to output data:

$$Task_i^l : In_i^l \ \rightarrow\ Out_i^l,\ l = \overline{1,n_l},\ i = \overline{1,n_i}\ . \quad (2)$$

where In_i^l, Out_i^l - input and output data correspondingly of the i^{th} task of the l^{th} level.

When systems concept is used according to TP optimization problem, a rational sequence of the whole task complex resolving is determined (1). The technology of TE system optimization task resolving is based on the ideas of aggregation-decomposition concept, of system analysis and of system design of a complex systems [11].

For the TP system optimization scheme creation S_{TP} it's necessary to define the five sets:

$$S_{TP} = \langle Tasks, InDat, Res, DesDec, ProcDec \rangle,$$

where $Tasks = \{ Task_i^l \},\ l = \overline{1,n_l},\ i = \overline{1,n_i}$ - the ordered set of tasks (1), *InDat* – the set of the input data of the task (1), *Res* – the set of the task's restrictions (1), *DesDec* – the set of the optimized decisions, *ProcDec* – the decisive procedure, that sets for each input data and restriction pare $< InDat_i^l, Res_i^l >$, nor empty subset of optimized decisions $\{ DesDec_i^{n_l} \}$, $i = \overline{1,n_i}$.

All tasks (1) from the *Tasks* set are completely solved, if for all tasks $Task_i^{n_l}$ optimization procedures $ProcDec_i^{n_l}$ are exist and each optimized decision $DesDec_i^{n_l}$ is the only one

$$\left| ProcDec_i^{n_l}(InDat_i^{n_l}, Res_i^{n_l}) \right| = 1 \quad \forall i = \overline{1,n_i}\ .$$

During the process of the interrelations analysis of system optimization problems of TP (1) each of their models is given as:

$$ModTask_i^{n_l} : \{ InDat_{iE}^{n_l},\ InDat_{iI}^{n_l},\ Res_i^{n_l} \} \rightarrow$$

$$\rightarrow\ DesDec_i^{n_l},\ i = \overline{1,n_i}\ ,$$

where $InDat^{n_l}_{iE}$ - the set of an external input data in a relation to task complex (1), $InDat^{n_l}_{iI}$ - the set of an internal input data in a relation to task complex (1), $Res^{n_l}_{i}$ - the set of the restrictions of the i^{th} task, $DesDec^{n_l}_{i}$ - the solution of the i^{th} task.

After the results of the tasks complex analysis (1) it has been determined, that an external in a relation to them input data $InDat^{n_l}_{iE}$ for all tasks $i=\overline{1,n_i}$ are the same [11]. The analysis of the input and output data of the system optimization tasks models $ModTask^{n_l}_{i}$, $i=\overline{1,n_i}$ displayed, that they all are dependent between each other by internal input and output data. Proceeding from it, it's reasonable to build the technology of the total system optimization task resolving on the basis of the consecutive iterative scheme.

At the same time, from received optimized solution $DesDec^{n_l}_{i}$ of the immediate task $Task^{n_l}_{i}$, $i=\overline{1,n_i-1}$ input data $InDat^{n_l}_{i+1}$ and restrictions $Res^{n_l}_{i+1}$ in decisive procedures $ProcDec^{n_l}_{i+1}$ for future tasks $Task^{n_l}_{i+1}$ would form. In such a way "short circuit" of the consecutive scheme tasks would be done:

$$\exists\, DesDec^2_i \in DesDec: Tr(\, InDat^2_{i+1} \vee Res^2_{i+1} \in DesDec^2_i\,),$$

$$i=\overline{1,n_i-1},$$

where *DesDec* – the set of optimized solutions, *Tr (True)* – validity of a statement $(InDat^{n_l}_{i+1} \vee Res^{n_l}_{i+1} \in DesDec^{n_l}_{i})$.

On the basis of formalization of the TP's creation purpose (3) and its decomposition to a complex with an interconnected tasks, a net model of the system optimization task is suggested. On the basis of a net model, a system optimization logical scheme is created, which allows to define a rational sequence of the resolving whole TP's system optimization task complex.

In the TC modelling process, the ideas of system task analysis [12] and ideas of the information modelling [7] have been used. Technological chain is given as information channel, where an information about preparations and accessories is coming at. That information consistently turns, to the information about the finished product (fig.1).

Let it designate as $X=\{X^{(i)}\}$, $i=\overline{1,n_I}$ the set of the parameters, that characterize preparations and accessories, and as $Y=\{Y^{(j)}\}$, $j=\overline{1,n_O}$ - the set of parameters, that characterize a finished product. Then: $H(X_1), H(X_2),\ldots, H(X_n)$ - an information amount, that is put into preparations and accessories parameters X after the first, the second and the, n^{th} operations; $H(Y)$ - an information amount, that is put into a finished product parameters Y; $I(X_n) \Rightarrow Y/X_1, X_2,\ldots,X_{n-1}$ - an information amount, that was transferred to a finished product parameters Y from preparations and accessories after *n* operations.

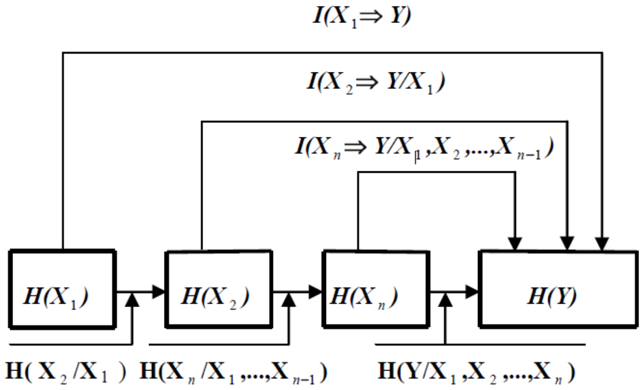

Fig. 1. The information scheme of the technological chain

On this basis a system of the equations is formed. This system allows to define a consecutive gain of information, that is transferred to input parameters after each operation in technological chain [7]:

$$\begin{cases} I(X_1 \to Y) = H(Y) - H(Y/X_1); \\ I(X_2 \to Y/X) = H(Y/X_1) - H(Y/X_1 X_2); \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ I(X_n \to Y/X_1,\ldots,X_{n-1}) = H(X_1,\ldots,X_n), \end{cases} \quad (3)$$

where $I(X_n \to Y/X_1,\ldots,X_{n-1})$ – an information amount about preparations and accessories parameters X after the n^{th} operation, which is a part of the output information, that characterizes Y; $H(Y)$ – an information amount (an entropy) about parameter Y, which contains in finished products; $H(Y/X_1 X_2)$ – an information amount (an entropy), got as a result of action at Y unaccounted factors.

Components ration, that are a part of the information about Y, will depend from extent of influence as input parameters X, as unaccounted factors, which influence at output parameters Y.

If the input parameters influence X after the k^{th} operation at the output parameters Y is absent, then

$$I(X_i) \to Y \mid X_1 X_2,\ldots,X_{i-1}) = 0;$$

$$H(Y) = H(Y \mid X_1 X_2,\ldots,X_{i-1}).$$

It corresponds a case of a full uncertainty of the obtained information according to the output parameters Y.

If information about the output parameters Y is completely defined by parameters X after the i^{th} operation, then:

$$H(Y) = H(Y \mid X_1 X_2,\ldots,X_{i-1});$$

$$I(X_i \to Y \mid X_1 X_2,\ldots,X_{i-1}) = 0.$$

Considering that:

$$H(Y \mid X_1 X_2,\ldots,X_n) = I(Y, X_1 X_2,\ldots,X_n) -$$
$$-H(X_1 X_2,\ldots,X_n),$$

system of the equations (3) could be represented as [7]:

$$\begin{cases} I(X_1 \to Y) = H(X_1) + H(Y) - H(X_1Y); \\ I(X_2 \to Y|X_1) = H(X_1X_2) - H(X_1X_2Y) - H(X_1) + H(X_1Y); \\ I(X_3 \to Y||X_1X_2) = H(X_1X_2X_3) - H(X_1X_2X_3Y) - \\ -H(X_1X_2) + H(X_1X_2Y); \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ I(X_n \to Y|X_1X_2...X_{n-1}) = H(X_1X_2...X_n) - \\ -H(X_1X_2...X_nY) - H(X_1X_2...X_{n-1}) + H(X_1X_2...X_{n-1}Y). \end{cases} \quad (4)$$

Extent of influence of the parameters X that are turned to parameters Y after each operation, in a context of the information modelling is possible to estimate with the information communication coefficient R_I :

$$\begin{cases} R_I(X_1 \to Y) = I(X_1 \to Y)/H(Y); \\ R_I(X_2 \to Y) = I(X_2 \to Y/X_1)/H(Y); \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots \\ R_I(X_n \to Y) = I(X_n \to Y/X_1,...,X_{n-1}))/H(Y). \end{cases} \quad (5)$$

From a system of the equation (5) follows, that: information communication coefficient $R_I = 1$, if the information about the finished product is completely defined by the information about preparations and accessories; $R_I = 0$, if parameters of the finished product don't depend from preparations and accessories parameters; in a general case $0 < R_I < 1$.

IV. Summary

Modern production technological processes are complex objects that are dispersed territorially or spatially. The problem of their system optimization provides the solution of a complex of tasks of structural, functional, parametrical and topological synthesis, which belong to different hierarchical levels of decomposition. The logical scheme of the technological processes system optimization as territorially distributed objects is suggested. As the scheme specification for efficiency assessment and decision choice, the information model of the technological chain is suggested, which allows not only display the formation process of the finished product quality, but also to estimate quantitatively the influence of each technological operation for its formation.

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