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MAIN STAGES OF AUTOMATED SYSTEM OF PROCESSES FOR DETERMINING AND ENSURING FUNCTIONAL AND PARAMETRIC COMPATIBILITY OF PRODUCTION AND TECHNOLOGICAL SYSTEMS

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Annotation: This article presents the main stages of the development of an automated system of processes for determining and ensuring functional and parametric compatibility (FPC) of components of production and technological systems (PTS), in particular production and technological modules (PTM) of machine-building production, respectively based on the analysis and systematization of technological zones of loading of the main technological equipment (MTE) and the construction of coating surfaces, the main parameters of industrial robots and storage systems (SS), determination and mathematical formalization of coating surfaces and guiding planes of MTE loading zones, formation of types of analytical dependences of FPC PTM functions, development of a mathematical model for automating the processes of determining and providing FPC of PTM components. The present developed automated system can be used in the processes of restructuring and modernization of domestic machine-building production systems by automating the processes of building optimal production and technological structures of various hierarchical levels for the purpose of information, technological and functional-parametric integration of domestic and foreign production structures of mechanical engineering.

Key words: automatization, automated system, compatibility, production, analysis, industrial robot, mathematical formalization.

Annotation: Ишда ишлаб чиқилиш-технологик тизимлари (ИЧТТ), хусусан, машинасозлик ишлаб чиқилишининг ишлаб чиқилиш-технологик модуллари (ИЧТМ) ниге компонентларини функционал-параметрик мосллиги (ФСМ)ни анықлаш ва таъминлаш эъронларинин автоматлаштирилган тизимларини асосий технологик жиҳозлар (АТЖ) ва сиртий қоплаш, юклашнинг технологик соҳалари, саноат роботлари ва тўплаб тизимлар (ТТ) ниге асосий параметрларини таъҳил қилиш ва таъминлаштириш, АТЖ ларнинг юклаш соҳалари ва сиртий қоплашларини аниқлаш ва математик ифодалаш, ИЧТМ ФСМ функцияларининг аналитик боғлиқлиги турларини шакллантириш, ИЧТМ компонентларининг ФСМ ни аниқлаш ва таъминлаш эъронларини автоматлаштириш математик моделларини ишлаб чиқиш асосида ҳаммасининг асосий босиқларини қатламлиш. Ишлаб чиқилишинин автоматлаштирилган тизимлардин мосллиги ва хорижий машинасозлик ишлаб чиқилишининг структуралисания бахорат, технологик ва функционал-параметрик ичқини калибдан турли ишларига саҳтли оптикал ишлаб чиқилиш-технологик структураларини қуриш эъронларини автоматлаштириш айл билан мамлакатимиз машинасозлик ишлаб чиқилишининг структураларини ахборот, технологик ва функционал-параметрик ичқини калибдан турли ишларига саҳтли оптикал ишлаб чиқилиш-технологик структураларини қуриш эъронларини автоматлаштириш айл билан мамлакатимиз машинасозлик ишлаб чиқилишининг структураларини ахборот, технологик ва функционал-параметрик ичқини калибдан турли ишларига саҳтли оптикал ишлаб чиқилиш-технологик структураларини қуриш эъронларини автоматлаштириш айл билан мамлакатимиз машинасозлик ишлаб чиқилишининг структураларини ахборот, технологик ва функционал-параметрик ичқини калибдан турли ишларига саҳтли оптикал ишлаб чиқилиш-технологик структураларини қуриш эъронларини автоматлаштириш айл билан мамлакатимиз машинасозлик ишлаб чиқилишининг структураларини ахборот, технологик ва функционал-параметрик ичқини калибдан турли ишларига саҳтли оптикал ишлаб чиқилиш-технологик структураларини қуриш эъронларини автоматлаштириш айл билан мамлакатимиз машинасозлик ишлаб чиқилишининг структураларини ахборот, технологик ва функционал-параметрик ичқини калибдан турли ишларига саҳтли оптикал ишлаб чиқилиш-технологик структураларини қуриш эъронларини автоматлаштириш айл билан мамлакатимиз машинасозлик ишлаб чиқилишининг структураларини ахборот, технологик ва функционал-параметрик ичқини калибдан турли ишларига саҳтли оптикал.
параметров промышленных роботов и накопительных систем (НС), определения и математической формализации поверхностей покрытий и направляющих плоскостей зон загрузки ОТО, формирования видов аналитических зависимостей функций ФПС ПТМ, разработки математической модели автоматизации процессов определения и обеспечения ФПС компонентов ПТМ. Разрабатываемая автоматизированная система может быть использована в процессах реструктуризации и модернизации отечественных машиностроительных производственных систем путём автоматизации процессов построения оптимальных производственно-технологических структур различного иерархического уровня с целью информационной, технологической и функционально-параметрической интеграции отечественных и зарубежных производственных структур машиностроения.

Ключевые слова: автоматизация, автоматизированная система, совместимость, производство, анализ, промышленный робот, математическая формализация.

Introduction

The main stages of the development and creation of automated systems for determining and providing FPC are [1]: analysis and systematization of technological zones of loading of the main technological equipment (MTE) on the basis of construction of coating surfaces, analysis and systematization of the main parameters of industrial robots and storage systems (SS), definition and mathematical formalization of coating surfaces and guide planes, definition of the functions of the FPC of production and technological modules (PTM), development of a mathematical model definition and provision of FPC components of production and technological modules.

1. Analysis and systematization of technological zones of loading of the main technological equipment (MTE) based on the construction of coating surfaces. One of the main technological conditions that determine the correctness of solving the scientific problem of developing effective PTM layouts is the consideration of functional-parametric indicators that express the interaction of PTM components with each other.

![Pic. 1. A fragment of the classifier of the loading zones with an analytical description of the coating surfaces.](image)

An important factor that determines the possibility of effective operation of the IR as part of the PTM is its correct functional and parametric combination with the MTE and SS in the entry and exit positions. The latter depends entirely on the design and functionality of the PTM components themselves. At the same time, the main factor that directly affects the efficiency of the PTM operation is the design in the MTE loading zone, in which the parts are processed, as well as the SS loading zone [1].
Based on the above, the work on the analysis of the MTE loading zones of turning, milling, drilling, boring, welding and grinding groups was carried out from the standpoint of determining the possible variety of structural design of the loading zones. The analysis confirmed the correctness of the developed classifier of zone varieties according to the principle of degrees of availability, given in [2]. The existing variety of load zones for processing MTE is classified into 12 groups according to the degree of availability. Although the classification meets the requirements of the rules of mathematical formalization of technical objects based on the important feature of accessibility to the loading zone, it cannot be used to build algorithms for machine synthesis and analysis of PTM layout solutions, since it is not based on analytical approaches.

2. Analysis and systematization of the main parameters of industrial robots and SS. Let an industrial robot (IR) have N coordinate movements and each \(i\)-th movement corresponds to different fixed values of speed and \(v_i^k\), where \(i = 1, N, k = 1, n_i\). Let us consider the formulation and solution of the problem of determining the number of combinations of manipulative movements of the gripping device of the working hand of the IR on the example of a two-link mechanism, which ultimately expresses the number of trajectories of the transferred part.

Let each link of the pair performs a rectilinear or translational motion and the first conditional link of the pair is characterized by \(n_1\) fixed values of velocities \(v_1^1, v_1^2, \ldots, v_1^{n_1}\), the second by \(n_2\) fixed values of velocities \(v_2^1, v_2^2, \ldots, v_2^{n_2}\).

Determination of the number of combinations of movements of the links of the pairs of the working hand of the IR, according to the types of combinations (Table 1.).

**Table 1.**

<table>
<thead>
<tr>
<th>Types of combinations</th>
<th>Diagram of a pair of links</th>
<th>Type of combinations Movements</th>
<th>Graphical representation of trajectory combinations movements</th>
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</thead>
<tbody>
<tr>
<td>Sequential execution of movements by a pair of links in time.</td>
<td>Graphical representation of trajectory combinations movements</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(S_I\) and \(S_2\) – working hand links of IR.
3. Definition and mathematical formalization of coating surfaces and guide planes. The complexity of solving this problem lies in the fact that the loading zones of the main processing equipment are diverse in their shape and size, and the IR is a complex mechanism in its kinematic scheme. Therefore, it is necessary to develop a suitable mathematical apparatus that would ensure the construction of such a trajectory of movement of the working arm of the IR, which would ensure the fulfillment of technological requirements.

To this end, this paper introduces the concept of the obstacle covering surface, which can be described in an analytical form. These surfaces are associated with typical zones of processing equipment, the coefficients of which depend on the size of the loading zone of the equipment. The number of such coating surfaces depends on the number of limiting obstacles in the MTE loading zones. To determine the various possible trajectories of the working arm of the IR, connecting two points of the IR (these two points correspond, for example, C_{CNC} and HC_1, HC_2 and C_{CNC}) we introduce the concept of a guide plane [3, 4].

A surface covering \( \Omega \) an obstacle \( P_{1i} \), is a surface that completely includes the obstacle \( P_{1i} \).

The guiding plane \( R_1 \) of the movement of the working hand IR and from one point to another, we call an arbitrary plane passing through these points.

The loading zones, depending on the number of planes bounding them, have the same number of coating surfaces, respectively [5].

4. Definition of the functions of the FPC PTM. To determine the function of the FPC PTM, we use the results of [6]:

\[
\Delta^{(i)}(t) = \Delta_{12}^{(i)}(t) \Delta_{12}^{(i)}(t) \Delta_{12}^{(i)}(t), \quad 0 < t < T_0
\]

where

\[
\Delta_{12}^{(i)}(t) = \frac{\partial W(x, y, z)}{\partial x} \partial P(x, y, z) / \partial y - \frac{\partial W(x, y, z)}{\partial y} \partial P(x, y, z) / \partial x
\]

\[
R = R_0^{(i)}(t)
\]

\[
\Delta_{23}^{(i)}(t) = \frac{\partial W(x, y, z)}{\partial y} \partial P(x, y, z) / \partial z - \frac{\partial W(x, y, z)}{\partial z} \partial P(x, y, z) / \partial y
\]

\[
R = R_0^{(i)}(t)
\]

\[
\Delta_{31}^{(i)}(t) = \frac{\partial W(x, y, z)}{\partial z} \partial P(x, y, z) / \partial x - \frac{\partial W(x, y, z)}{\partial x} \partial P(x, y, z) / \partial z
\]

\[
R = R_0^{(i)}(t)
\]

where \( R_0^{(i)}(t) = (x_0^{(i)}(t), y_0^{(i)}(t), z_0^{(i)}(t)) \) – radius-vector of some point of the \( i \) -th link relative to the coordinate system \( O_0x_0y_0z_0 \) associated with the fixed base of the auxiliary equipment \( R = (x, y, z) \) – an arbitrary vector defined relative to the coordinate system \( O_0x_0y_0z_0 \) and associated with the fixed base of the auxiliary equipment.

As a result, we have functional-parametric compatibility \( \Delta^{(i)}(t), (i = 1, 2, \ldots, n) \) functions for all parts \( P_1, P_2, \ldots, P_n \) of the auxiliary equipment [7,8,].

5. Development of a mathematical model definition and provision of FPC components of production and technological modules (PTM). Functional-parametric compatibility of MTE and IR can be implemented in various ways, depending on the choice of the corresponding trajectories of movement of the IR gripper device from one position to another, determined by using different coordinate displacements.

Applying the method proposed in [9,10,11], we define
The solution of the problem is different, if there is a single \( s \) for which the condition is met \( \Delta_{ij}(t) \neq 0 \), then \( s_i \) and \( r_j \), functionally-parametrically compatible in the process of functioning \( m_{ij} \) in a certain time interval \( (t_{ij} < t < T_{ij}) \). If for all \( s \) \( \Delta_{ij}(t) = 0 \), then they are not compatible.

The solution of the problem is different, if there is a single \( s \) for which it is performed \( \Delta_{ij}(t) \neq 0 \), then we can conclude that their functional-parametric combination can be carried out in the only way, i.e. there is a single trajectory of movement of the gripper device IR from the position of the MTE loading to the position of the SS loading, along which their functional-parametric combination can be carried out.

If for function \( \Delta_{ij}(t) (j_s = 1, n_s) \) the conditions are met \( \Delta_{ij}(t) \neq 0 \), \( \Delta_{ij}(t) \neq 0 \), \( \cdots \), \( \Delta_{ij}(t) \neq 0 \), this means that their functional-parametric compatibility can be implemented \( j_s \) in the following way. In this case, the solution of the problem requires additional research. Now we will proceed to the formation of functionally-parametrically compatible PTM structures.

Let \( \Delta_{ij}(t) (j_s = 1, n_s) \) – functional-parametric compatibility function \( s_i \) and \( r_j \). If exists \( j_s (j_s = 1, n_s) \), which is being executed for \( \Delta_{ij}(t) \neq 0 \), \( (t_{ij} < t < T_{ij}) \), then we assume that MTE \( s_i \) and IR \( r_j \) functionally-parametrically compatible and form a PTM \( m_{ij} \).

If for all \( j_s (j_s = 1, n_s) \) the conditions are met \( \Delta_{ij}(t) = 0 \), \( (t_{ij} < t < T_{ij}) \), then \( s_i \) and \( r_j \) the formation of the module is also functionally and parametrically incompatible \( m_{ij} \), impossible.

Repeating this procedure for all elements \( P = \{(s_i, r_j): j_s = 1, n_s, i = 1, m, s = 1, k\} \), you can choose functionally-parametrically compatible PTM structures that make up a certain set \( P_{FPC} \in P \), the elements of which meet the requirements of the functional-parametric compatibility [12,13,14].

Repeating this procedure for all elements \( P = \{(s_i, r_j): j_s = 1, n_s, i = 1, m, s = 1, k\} \), you can choose functionally-parametrically compatible PTM structures that make up a certain set \( P_{FPC} \in P \), the elements of which meet the requirements of functional-parametric compatibility. At the stage of systematization of information about IR and MTU, the corresponding analytical descriptions of the surface of the coating of the loading zone (processing) are systematized) MTU and the guiding plane, as well as the number and
type of coordinate movements, analytical descriptions of the trajectories of the gripper device of the PR, etc. are determined.

At the next stage, the values of the functional-parametric compatibility function are calculated based on the information about the IR and MTU $\Delta_{ij}(t)$. $(j_s = 1, n_s, i = 1, m, s = 1, k)$.

Then, using the results of the second stage, the conditions are checked. $\Delta_{ij}(t) \neq 0$, $(j_s = 1, n_s, i = 1, m, s = 1, k)$ and the functional-parametric compatibility of IR and MTU is determined; the components of PTM are combined taking into account their functional-parametric compatibility and their functionally-parametric compatible structures are formed, forming a certain set $P_{FPC}[15,16]$.

**Conclusion**

The developed automated system can be used in the processes of restructuring and modernization, as well as for the integration of domestic and foreign machine-building production systems by automating the processes of building optimal production and technological structures of various hierarchical levels in order to ensure information, technological and functional-parametric compatibility of local and foreign machine-building production structures. Also to applying organizational, technological and structural decisions on the integration of PTM with the provision of functional and parametric compatibility of their components, which is the basis for the implementation of tasks for the formation of production structures of a higher organizational level.

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