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# FORMALIZATION OF KINEMATIC STRUCTURES SYNTHESIS OF PRODUCTS DISASSEMBLY MECHATRONIC SYSTEMS AT THE COMPLEX EQUIPMENT REPAIR STAGE

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*This work is devoted to the process of formalizing the search for a rational version of the layout solution for mechatronic disassembly systems. Based on the developed models for disassembling products and the kinematics of industrial robots, it became possible to select a robot with an appropriate degree of mobility in an automated mode. The next step in the selection of industrial robots is to analyze the feasibility of the task, taking into account the accuracy, weight and dimensions of the disassembled elements. For disassembling products, those robots are selected whose technical characteristics allow disassembly taking into account the characteristics in question. The robots are ranked based on their value. Robots with the lowest cost have the first rank. If the robot in question does not meet the selection criteria or the structure of the production site does not coincide with the structure of the disassembly technological scheme, then a robot with a large rank is selected and the analysis of production manufacturability is performed again.*

*From the point of view of disassembly technology, a product is a set of types of connections of its parts. The process of transformation of the type of connection during operation is influenced by a number of factors: – operation time; – operating conditions; – the degree of residual impact on the environment.*

*The developed technological models of geometric and kinematic movements of products and executive bodies of robots adequately describe the location of the disassembled parts in space and their movements during disassembly. The classification of industrial robots on the basis of their structural and kinematic characteristics makes it possible to select them, taking into account the necessary kinematics and accuracy when disassembling joints, the robot's carrying capacity and the ability to work with objects of certain dimensions. The main idea of the concept presented in the work is to develop a methodology for a systematic approach to the design of highly efficient technological systems used in the reconstruction, modernization and restoration of the operability of technical means and objects of material production in mechanical engineering.*

***Key words:*** *technological system, simulation, structural synthesizing, mechatronic systems, selective disassembly, kinematic movements, robots, optimization.*

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**Introduction**

Analysis of modern technologies for the repair of equipment shows a significant difference in the level of technological equipment and technologies that are used in industrial and repair enterprises. At the stage of repair, the complexity of solving problems is high due to the fact that the path to the place of the defect is original. This is one of the restrictions on the introduction of mechatronic systems into repair production. Therefore, the automation of the process of disassembling critical products is an urgent task.

**Formulation of the problem**

Among the whole variety of types of technological equipment, such systems can be distinguished into a separate group, which are subject to increased requirements for the safety of operation, maintenance and repair as a result of the specific features of their design and functional purpose. Examples of such equipment are high-power gas turbine engines, special equipment, nuclear power engines, including special-purpose vehicles, etc.

At the stage of reengineering of such products, that is, restoration of their performance, repair and modernization, it becomes necessary to disassemble the failed part (Konoplianchenko et al., 2017, c. 27; Konoplianchenko et al., 2017, c. 21). It is known that complete disassembly of equipment during repair or modernization is one of the undesirable operations, since even with qualified savings disassembly, the connection of worn-in parts and normal tension in grooves with fixed landings are disrupted (Tarelnyk et al., 2015). Some of the parts are damaged during disassembly (tides, quotes, flanges break, the edges of bolts and nuts are knocked off, cotter pins, rivets, etc.). Units and parts that do not require repair are generally not recommended to be removed from the equipment due to a possible decrease in the performance of the machines as a whole. Therefore, the issue of optimizing the access path to a failed unit or a worn-out part is relevant.

**Analysis of major achievements and publications**

When formalizing the solution to the problem of determining the sequence of disassembling a product, it is necessary to develop its mathematical model, select an optimization criterion, develop a system of indicators that limit the enumeration of a set of options, develop a method for solving the problem, present it mathematically, algorithmically and programmatically.

Sometimes in production practice, when determining the sequence of disassembly, a technological scheme for assembling a product is used. Most of the work is performed on the basis of the experience and intuition of the technologist.

The technological scheme for assembling a product is multivariate, depending on a number of factors and the optimization criteria used (Konoplyanchenko et al., 2002). Then the disassembly process will be directed in the same way. However, the conditions for disassembly and then assembly at the repair plant and the manufacturer of the product can differ significantly. The problem is not only in the availability of the necessary tools for technological equipment, but also in the cost of individual parts and assembly units, the likelihood of a defect-free disassembly of assembly joints, the qualifications of repair personnel, the cost of assembly operations to ensure the specified accuracy, tightness, etc. Therefore, the correct choice of approach to assembly an element or a failed part will significantly affect the operability of the repaired equipment and, accordingly, the cost of the technological process of repair.

In foreign literature, when formalizing the process of partial disassembly of products, the method of Gaussian hemispheres is used (Gupta S. M. & McLean C. R., 1996). The Gaussian sphere displays the permissible directions of the movement vectors of the part of the product in free space. Since the surfaces of the parts are conjugated in assembly units, in reality they use not a sphere but a Gaussian hemisphere (Fig. 1, **a**), which reflects the possible directions of movement of the part during disassembly along the mating surface. Applying the techniques of Boolean algebra and mathematical logic, the problem of finding the directions of the product disassembly vectors is formalized with the help of Gaussian hemispheres. (Fig. 1, **b**).

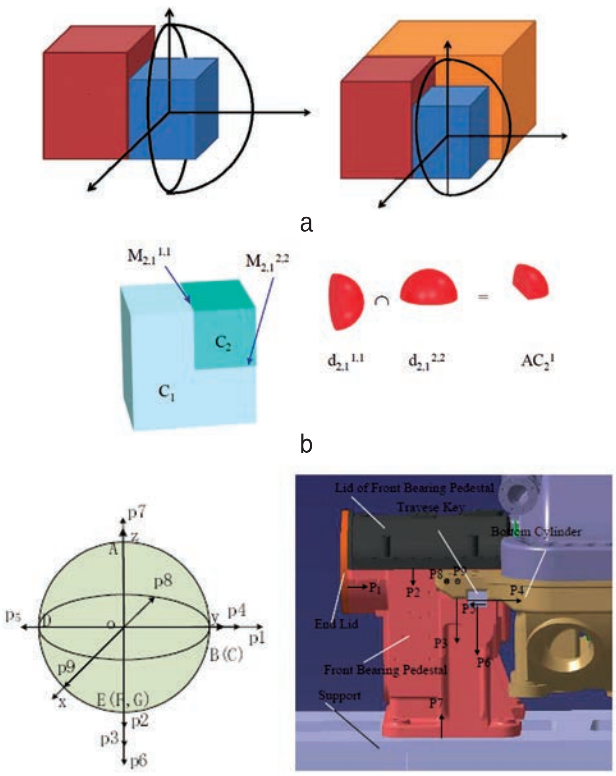



**Fig. 1. Simulation of the product disassembly process**

Figure 1,**c** shows the procedure for checking the separation of the compressor front bearing strut, where P1 – P9 are normal vectors connected surfaces for the front bearing support, points B, E, F, C, D, G and A are the points of intersection between these normal vectors and a sphere with a unit radius. Since there is no hemisphere that can accommodate all the points, the A-pillar support bearing cannot be disassembled in this state.

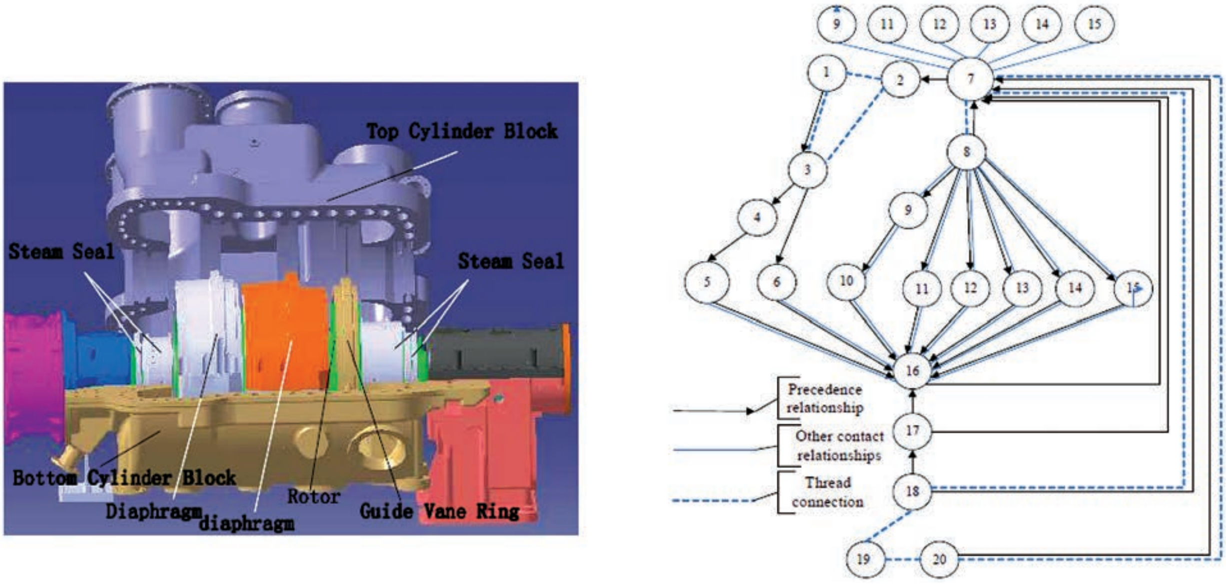



**Fig. 2. Graph of the planned sequence of dismantling a steam turbine for a virtual service system**

To date, a number of models and algorithms are known that are used to generate assembly and disassembly sequences of a product (H.C. Yi et al., 2003). Widespread use of disassembly and assembly sequences to formalize the generation has led to their representation in the form of AND-OR-graphs, connection graphs and Petri nets (NP) (Lakos C.A., 1995). In fig. 2 shows a simulation of the sequence of disassembling a steam turbine in a service system with elements of virtual reality (H. Zhu T. & Cong L., 2014).

The analysis of these works showed that the problem belongs to the class of NP-heavy, and, in fact, its solution is reduced to a complete enumeration or the use of the branch and bound method. Thus, it can be concluded that the existing analytical methods for generating assembly and disassembly sequences are of low efficiency.

A method called "Wave Propagation" has been widely used to formalize the generation of disassembly sequences, the essence of which is to determine the sequence of partial disassembly, minimized by the number of elements separated from the product, for specific operating conditions of the equipment (Gadh R. & Srinivasan H., 2000; Beasley D. & Martin R.R., 1993). Using this approach, two tasks are solved: – building a disassembly wave to determine the topology of access to the part, which needs to be disassembled; – determination of points of intersection of disassembly waves to form a variety of options for the disassembly sequence of the product. To implement a variety of options for solving the problem of disassembling a product, it is necessary to create an automated method for the synthesis of rational operating complexes capable of performing this task.

**Research methodology**

This work is devoted to the process of formalizing the search for a rational version of the layout solution for mechatronic disassembly systems.

To automate the synthesis process of a rational version of the structure, mathematical models of geometric and kinematic displacements of assembly elements and actuators of robotic assembly equipment were derived (Konoplianchenko et al., 2020, c.186; Konoplianchenko et al., 2020, c.125).

In order to describe mathematical models, we have introduced the following conventions for elements and events of the assembly process: **a** – covering part (sleeve); **b** – male part (shaft).

Restrictions: – part **a** is stationary, fixed in the device; – part **b** is positioned relative to part **a** by the executive bodies of the assembly equipment.

The displacement diagram illustrating the mathematical models is shown in Fig. 3.

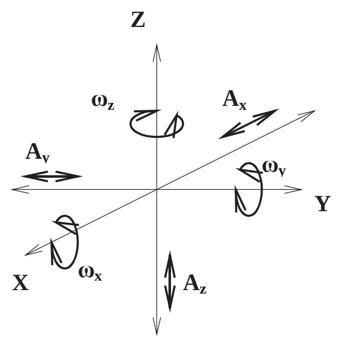



**Fig. 3. Scheme of geometric displacements of assembly elements.**

According to fig. The 3 main events in the build process are:

$A_x^a, A_y^a, A_z^a$ – linear movement of the part and along the axes (X, Y, Z);

$\omega_x^a, \omega_v^a, \omega_z^a$ – rotation of the part a around the axes (X, Y, Z);

$A_x^b, A_y^b, A_z^b$ – linear movement of the part b along the axes (X, Y, Z);

$\omega_x^b, \omega_y^b, \omega_z^b$ – rotation of the part b around the axes (X, Y, Z).

$S^{a,b}$ – connection of part **a** to part **b**.

Depending on the structural and kinematic diagram, industrial assembly robots are classified into 4 groups (Table 1).

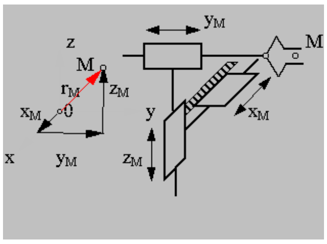
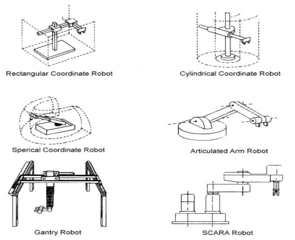
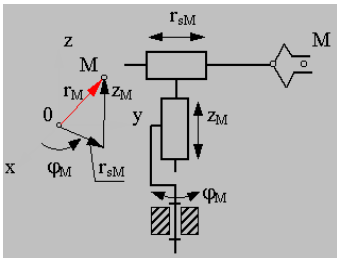
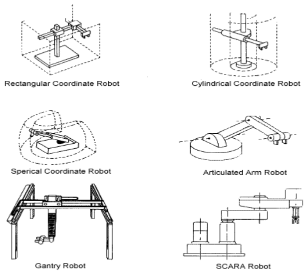
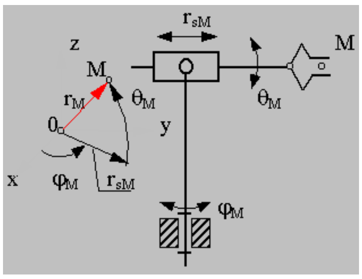
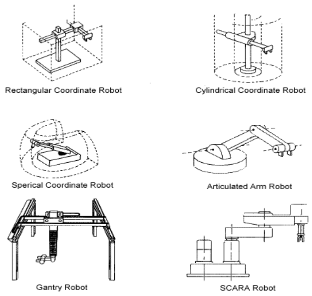
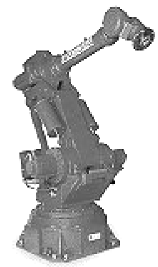
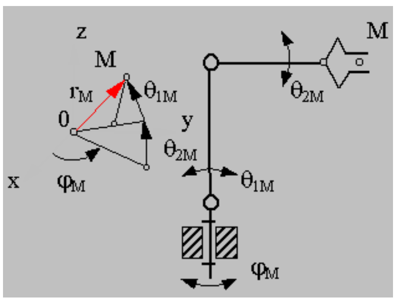
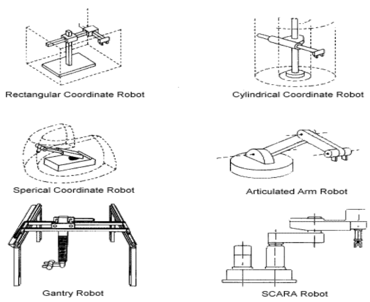
Based on the developed models for disassembling products and the kinematics of industrial robots, it became possible to select a robot with an appropriate degree of mobility in an automated mode.

The next step in the selection of industrial robots is to analyze the feasibility of the task, taking into account the accuracy, weight and dimensions of the disassembled elements. For disassembling products, those robots are selected whose technical characteristics allow disassembly taking into account the characteristics in question.

Next comes the selection of industrial robots by cost. When analyzing the manufacturability of the assembled products, first of all, those robots are selected that have a lower cost.

Table 1

**Classification of industrial robots.**

| **Kinematic diagram implementation** | **Block diagram of implementation** | **Characteristic representative** |
|---|---|---|
| Rectangular (Cartesian) coordinate system | | |
|  |  | Adept SmartCartesian<br> |
| Cylindrical coordinate system | | |
|  |  | Toshiba Machine SR-854HSP<br> |
| Spherical (polar) coordinate system | | |
|  |  |  |
| Kinematic diagram implementation | Block diagram of implementation | Characteristic representative |
| Angular coordinate system | | |
|  |  |  |

The robots are ranked based on their value. Robots with the lowest cost have the first rank. If the robot in question does not meet the selection criteria or the structure of the production site does not coincide with the structure of the disassembly technological scheme, then a robot with a large rank is selected and the analysis of production manufacturability is performed again.

According to the above classification of industrial robots (Table 1), for each class of robots it is possible to write down the condition for fulfilling the type of movement:

– rectangular (Cartesian) coordinate system

$$\underset{\theta\in M}{\exists} R_\theta = A_x^b \wedge A_y^b \wedge A_z^b ,$$

where $M = \{1,\ldots,\phi\}$ – many industrial robots of this class;

– cylindrical coordinate system

$$\underset{\theta\in M}{\exists} R_\theta = A_x^b \wedge A_y^b \wedge \omega_z^b ,$$

where $M = \{1,\ldots,\varphi\}$ – many industrial robots of this class;

– spherical coordinate system

$$\underset{\theta\in M}{\exists} R_\theta = \omega_x^b \wedge \omega_y^b \wedge A_z^b ,$$

where $M = \{1,\ldots,\tau\}$ – many industrial robots of this class;

– angular coordinate system

$$\underset{\theta\in M}{\exists} R_\theta = \omega_x^b \wedge \omega_y^b \wedge \omega_z^b ,$$

where $M = \{1,\ldots,\zeta\}$ – many industrial robots of this class.

To be able to implement each type of connection, taking into account the assembly equipment, it is necessary to describe the mathematical models of typical options for the gripping devices of manipulators. Table 2 presents mathematical models for the implementation of geometric displacements of typical gripping devices.

At the stage of synthesis of the layout solution of an industrial robot to implement a given type of connection, a logical expression is used as a condition for selecting a gripper:

$$\underset{\xi\in I}{\exists} K_\xi = \left(\left(\sim R_\theta \wedge S^{a,b}\right) \Rightarrow Z_\varpi\right),$$

where $I = \{1,2,\ldots,\lambda\}$ – many layout solutions.

The use of the developed methodology makes it possible to formalize the process of automated disassembly of the product, which makes it possible to introduce mechatronic systems at the stage of repairs and modernization of critical equipment.

Further research in this direction revealed that an important influence on the optimal variant of the disassembly sequence is carried out by: the availability of the necessary technological equipment and its cost; the cost of disassembly and assembly operations, debugging and control of individual machine units; the cost of individual parts included in the product; environmental safety of access to parts operating in conditions hazardous to humans.

The adaptation of the above methods consists in formalizing the process of disassembling products, taking into account the influence of both operating conditions on the product and taking into account the degree of impact of residual negative operational factors in the product on the environment (Konoplianchenko et al., 2017, c. 27).

From the point of view of disassembly technology, a product is a set of types of connections of its parts. The process of transformation of the type of connection during operation is influenced by a number of factors: – operation time; – operating conditions; – the degree of residual impact on the environment. Time factor – for a long time of operation of parts, even under normal conditions, a change in the type of connection occurs, associated, for example, with wear of friction pairs; configurations of physical parameters of parts in contact (drying out of rubber seals, magnetization of the contact surface, etc.). The factor of operating conditions is the influence of an aggressive environment, dustiness of the working area, thermal effects, heavy loads, operation in conditions of hard radiation (increased radiation), chemical, bacteriological and other types of contamination. The factor of the degree of residual impact on the environment – determines the degree of consequences of the impact of unfavorable operating conditions on the product as a whole and the parts included in it (in particular, explosion hazard, residual radiation, biological hazard, etc.). This is how the concept of resource-saving partial disassembly of the product is realized until the part is out of order or requires replacement.

Since the problem of finding a rational disassembly technology is invariant, that is, implemented by different methods or their combination, a model for synthesizing the optimal solution is required.

**RESULTS**

The set of solutions to this problem at the qualitative level is described by the equation (necessary condition):

$$\underset{\psi\in\Psi}{\forall} R_\psi = \{R \mid \gamma_R^{\min} \le \gamma_R \le \gamma_R^{\max}\} ,$$

those. for all existing options for solving the problem (a set of technologies), the established criteria for the quality of the process must be in the range of permissible values $\lambda_{P_0}^{\min} \le \lambda_{P_0} \le \lambda_{P_0}^{\max}$, to predict the likelihood of a defect-free disassembly of critical products, to ensure the specified accuracy, tightness, etc. In addition, one of the priority criteria is the environmental safety of access to parts that operate in conditions hazardous to humans and / or the environment.

By solving the problem at the technological level (sufficient condition):

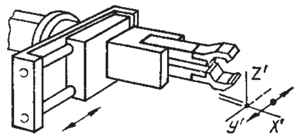
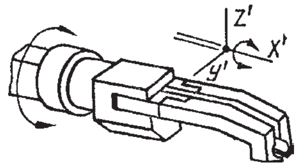
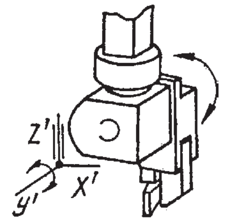
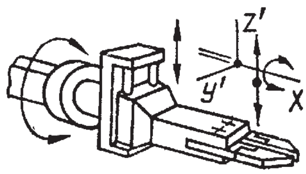
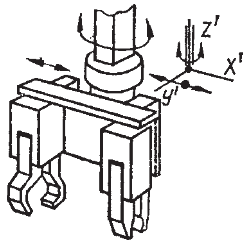
$$\underset{\xi\in\theta}{\exists} R_\xi = \bigcap_{\psi=1}^{\chi} R_\psi \vee \underset{\varphi=1}{\overset{\phi}{\exists}} M_\varphi \vee \underset{\zeta=1}{\overset{\chi}{\exists}} STO_\zeta \vee \underset{\varepsilon=1}{\overset{\tau}{\exists}} TP_\varepsilon ,$$

where $\underset{\xi\in\theta}{\exists} R_\xi$ – the existing solution to the problem; $\bigcap_{\psi=1}^{\chi} R_\psi$ – a set of options for solving the problem, satisfying the necessary condition; $\underset{\varphi=1}{\overset{\phi}{\exists}} M_\varphi$ – availability of methods for solving the problem for each option; $\underset{\zeta=1}{\overset{\chi}{\exists}} STO_\zeta$ – availability of technological equipment capable of implementing the necessary methods; $\underset{\varepsilon=1}{\overset{\tau}{\exists}} TP_\varepsilon$ - availability of the necessary technological modes for technological equipment for each method.

In this case, from the technological costs of the options for solving the problem that satisfies the necessary and sufficient

Table 2

**Implementation of geometric displacements by typical options for the layout of gripping devices**

| № | Example, sketch | Mathematical model of realizable displacements |
|---|---|---|
| 1. |   | $\underset{\varpi\in\Delta}{\exists} Z_\varpi = A_y^b$, where $\Delta$ – many devices of this type |
| 2. |   | $\underset{\varpi\in\Phi}{\exists} Z_\varpi = \omega_x^b$, where $\Phi$ – many devices of this type |
| 3. |   | $\underset{\varpi\in\Theta}{\exists} Z_\varpi = \omega_y^b$, where $\Theta$ – many devices of this type |
| 4. |   | $\underset{\varpi\in\Omega}{\exists} Z_\varpi = \left(\omega_x^b \wedge A_z^b\right)$, where $\Omega$ – many devices of this type |
| 5. |   | $\underset{\varpi\in\Xi}{\exists} Z_\varpi = \left(A_x^b \wedge \omega_z^b\right)$, where $\Pi$ – many devices of this type |
| 6. |   | $\underset{\varpi\in\Pi}{\exists} Z_\varpi = \left(\omega_x^b \wedge \omega_y^b\right)$, where $\Pi$ – many devices of this type |

condition, a set is formed, according to the expression (Konoplianchenko et al., 2013; Konoplianchenko, 2010):

$$\{C_{P_0}\} = \bigcup_{k\in X}\left\{C_{P_0}(k)\left|\begin{array}{l}\underset{\xi\in\theta}{\exists} R_\xi = \bigcap_{\psi=1}^{\chi} R_\psi \vee \underset{\varphi=1}{\overset{\phi}{\exists}} M_\varphi \vee \underset{\zeta=1}{\overset{\chi}{\exists}} STO_\zeta \vee \underset{\varepsilon=1}{\overset{\tau}{\exists}} TP_\varepsilon, \\ \underset{\psi\in\Psi}{\forall} R_\psi = \{R \mid \gamma_R^{\min} \le \gamma_R \le \gamma_R^{\max}\}\end{array}\right.\right\}$$

The optimization problem according to economic criteria (minimum technological cost) is then represented by the expression:

$$P_0^{opt} = \underset{C_{mex}\to\min}{\ell im} P_0 \left| C_{mex} \in \left\{C_{P_0}\right\}\right. .$$

## CONCLUSIONS

The developed technological models of geometric and kinematic movements of products and executive bodies of robots adequately describe the location of the disassembled parts in space and their movements during disassembly.

The classification of industrial robots on the basis of their structural and kinematic characteristics makes it possible to select them, taking into account the necessary kinematics and accuracy when disassembling joints, the robot's carrying capacity and the ability to work with objects of certain dimensions.

The main idea of the concept presented in the work is to develop a methodology for a systematic approach to the design of highly efficient technological systems used in the reconstruction, modernization and restoration of the operability of technical means and objects of material production in mechanical engineering.

Practical application of the proposed approach will improve the quality and safety of the process of repair and modernization of such complex equipment as special-purpose vehicles, and the introduction of a formalized methodology in real production conditions will increase the level and efficiency of the use of available technological equipment.

***References:***


1. Konoplianchenko, Ie. V., Kolodnenko, V. N. & Chibiryak, Ya. I. (2017). Feature of heavy-duty gas turbine compressor reengineering. *Kompressornoe i energeticheskoe mashinostroenie.* [Compressor and power engineering], 1(47), 27-30.

2. Konoplianchenko, Ie. V., Kolodnenko, V. N. & Chibiryak, Ya. I. (2017). Osoblyvosti zastosuvannia chasovoho rezervuvannia pry zabezpechenni nadiinosti skladnykh system. *Tekhnichnyi servis ahropromyslovoho, lisovoho ta transportnoho kompleksiv.* [Technical service of agro-industrial, forest and transport complexes], 8, 21-28 (in Ukrainian).

3. Tarelnyk, V., Antoszewski, B., Konoplianchenko, Ie. & Martsynkovskyi, V. (2015). Improvement of fixed joints quality by integrated technologies of electroerosive alloying. *Mechanik*, 4 (88), 178-183.

4. Konoplyanchenko, E., Zakharov, N., Radchuk, O. & Yaremenko V. (2002). Rational syntheses of technological processes of assembly. *Technical Papers of ISA: Integrated Manufacturing Solutions Real-Time Manufacturing Strategies*, 432,109–118.

5. Gupta S. M. & McLean C. R. (1996). Disassembly of Products. *Computers and Industrial Engineering*, 31(1), 225-228.

7. Yi, H.C., Yu, B., Du, L., Li, C. & Hu D. (2003). A study on the method of disassembly time evaluation of a product using work factor method. *Proceedings of the 2003 IEEE International Conferences on Systems. Man. Cybernetics*, 1753-1759.

8. Lakos, C. (1995). From Coloured Petri Nets to Object Petri Nets. In: De Michelis G., Diaz M. (eds) *Application and Theory of Petri Nets 1995. ICATPN 1995. Lecture Notes in Computer Science*, 935, 278-297. https://doi.org/10.1007/3-540-60029-9_45

9. Zhu, H. T. & Cong, L. (2014). Disassembly Sequence Planning of Steam Turbines for Virtual Maintenance. *Key Engineering Materials*, 572, 335-339. https://doi.org/10.4028/www.scientific.net/KEM.572.335

10. Gadh, R. & Srinivasan, H. (2000). Assembly and disassembly sequences of components in computerized multi-component assembly models. *U.S. Software Utility Patent*, P99152US.

11. Beasley, D., & Martin, R.R., (1993). Disassembly sequences for objects built from unit cubes. *Journal of Computer Aided Design*, 25(12), 751-761.

12. Konoplianchenko, Ie.V., Yaremenko, V.P., Song, Zh., Kolodnenko, V.M. & Balo, P.M. (2020). Formalizatsiya protsessa sinteza kinematiki mehanotronnyih sborochnyih tehnicheskih sistem. *Materialy Mizhnarodnoi naukovo-praktychnoi konferentsii «Molod i tekhnichnyi prohres v APV» Innovatsiini rozrobky v ahrarnii sferi (07-08 travnia 2020 roku).* [Proceedings of the International Scientific and Practical Conference “Youth and Technical Progress in AIC” Innovative developments in the agricultural sector (May 07-08, 2020)], 2, 186-189 (in Russian).

13. Konoplianchenko, Ie.V., Yaremenko, V.P., Herasimenko, V.O. & Liu Dongmei.(2020). Povyishenie effektivnosti protsessa remonta slozhnoy tehniki vnedreniem mehatronnyih sistem razborki izdeliy. *Materialy mizhnarodnoi naukovo-praktychnoi konferentsii «Ekspluatatsiina ta servisna inzheneriia» (28-29 travnia 2020 roku).*[ Proceedings of the International Scientific and Practical Conference “Operational and Service Engineering” (May 28-29, 2020)], 125-128 (in Russian).

14. Konoplianchenko, Ie.V., Herasimenko, V.O. & Kolodnenko, V.M. (2013). Obespechenie kachestva reinzhiniringa slozhnoy tehniki vnedreniem resursosberegayuschih CALS-tehnologiy v remontnom proizvodstve. *Visnyk KhNTUSH. Tekhnichnyi servis mashyn dlia roslynnytstva.* [Bulletin of KhNTUSG. Technical service of machines for crop production], 134, 80-86 (in Russian).

15. Konoplianchenko Ie.V. (2010). Obespechenie resursosberezheniya slozhnoy tehniki na etape remonta napravlennyim vyiborom tehnologii ee razborki. *Visnyk KhNTUSH. Problemy nadiinosti mashyn ta zasobiv mekhanizatsii silskohospodarskoho vyrobnytstva.* [Bulletin of KhNTUSG. Problems of reliability of machines and means of mechanization of agricultural production], 100, 317– 321.



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***Формалізація синтезу кінематичних структур мехатронних систем розбирання виробів на етапі ремонту складної техніки***


*Цю роботу присвячено процесу формалізації пошуку раціонального варіанту компонувального рішення для мехатронних систем розбирання. На основі розроблених моделей розбирання виробів і кінематики промислових роботів стало можливим вибрати робота із відповідним ступенем мобільності в автоматизованому режимі. Наступним кроком у виборі промислових роботів є аналіз доцільності виконання завдання з урахуванням точності, ваги і розмірів елементів, що розбираються. Для розбирання виробів вибирають таких роботів, технічні характеристики яких дозволяють розбирати з урахуванням розглянутих характеристик. Роботи ранжуються за їхньою вартістю. Роботи із найменшою вартістю мають перший ранг. Якщо робот не відповідає критеріям відбору, або структура виробничої ділянки не збігається зі структурою технологічної схеми розбирання, то вибирають робота більшого рангу і знову проводять аналіз технологічності виробництва.*

*Із погляду на технологію розбирання виріб представляється як сукупність видів з'єднань його частин. На процес трансформації типу з'єднання під час експлуатації впливає низка факторів: час роботи, умови роботи, ступінь залишкового впливу на навколишнє середовище.*

*Розроблені технологічні моделі геометричних і кінематичних переміщень виробів і виконавчих органів роботів адекватно описують розташування у просторі деталей, що розбираються, та їхнє переміщення під час розбирання. Класифікація промислових роботів за їхніми конструктивними і кінематичними характеристиками дозволяє виділити їх із урахуванням потрібної кінематики і точності під час розбирання з'єднань, вантажопідйомності робота і можливості роботи з об'єктами певних розмірів. Основна ідея представленої у роботі концепції полягає у розробленні методології системного підходу до проєктування високоефективних технологічних систем, що використовуються під час реконструкції, модернізації і відновленні працездатності технічних засобів та об'єктів матеріального виробництва у машинобудуванні.*

***Ключові слова:*** *технологічна система, моделювання, структурний синтез, мехатронні системи, часткове розбирання, кінематичні переміщення, роботи, оптимізація.*

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