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ADVANCED PROSPECTS FOR THE DEVELOPMENT OF AIRCRAFT ASSEMBLY TECHNOLOGY

On the basis of theoretical studies carried out by the method of virtual bases, the concept for automated assembly of aircraft structures, specialized CNC re-adjustable devices, and robotic systems has been developed. The principles for automated assembly with the use of robotic system to be implemented at aircraft-building corporations have been substantiated.

Keywords: automated assembly production, robotic systems, specialized CNC re-adjustable devices, and method of virtual bases.

In recent years, a rapid progress in the aviation science and technology has allowed the engineers to design aircraft capable of flying at hypersonic speeds, in all weather conditions, transporting up to 525 passengers between the continents, and lifting up to 250 tons of cargo being controlled by onboard computer. The passenger and cargo aircraft are manufactured by relatively small series with an extremely wide nomenclature of assembly units. In addition, there are light general aviation aircraft that currently make up 97% of the world civil aviation fleet.

Modern aircraft are designed by means of computer integrated technologies CAD/CAM/CAE (Fig. 1), with a large part of equipment manufactured using computer numerical control (CNC). However, assembly tooling is installed and commissioned manually, with the share of related costs in the total labor input of aircraft manufacture being 40% [1].

The operations on mutual coordination of parts and components during their installation (location and fixation) in the assembly position, as well as the connection of components and the manufacture of the second order hardware have a significant share in the costs related to the assembly works. These costs are largely determined by a significant amount of manual work and depend on design features, technological level, breakdown configuration, assembly techniques, and interoperability. The growth in output is achieved mainly by expanding the scope of work and increasing the number of workers employed in the industry.

Among the reasons for a high labor intensity and cost of assembly operations in the aviation industry, as well as for a long duration of manufacturing cycle, there are time low level of mechanization and automation of assembly operations, as well as the use of outdated traditional methods for assembly and alignment based mainly on special assembling jigs.

In view of the above mentioned factors, the development and introduction of aircraft automated assembly by improving the existing alignment and assembly techniques and developing new ones based on the use of specialized, re-adjustable devices with software control and robotic systems are actual engineering problem.

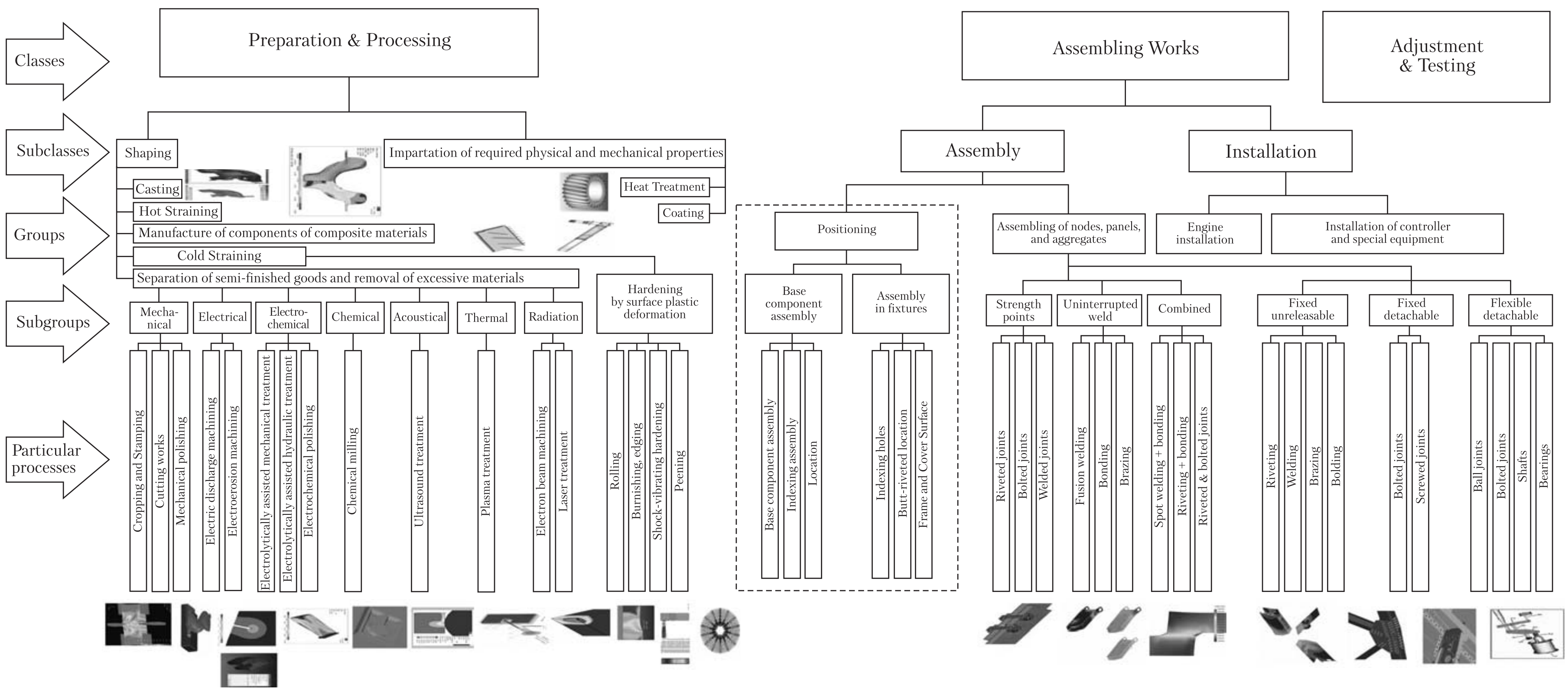

Fig. 1. Classification of processes in the aircraft manufacture

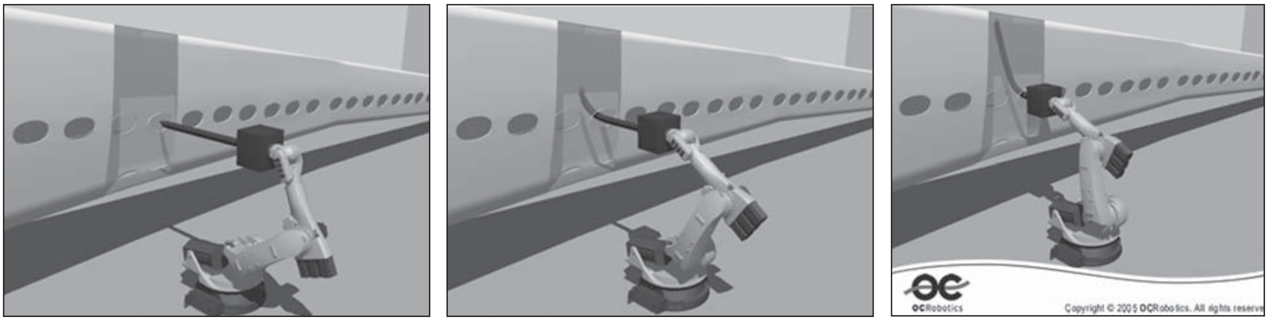

Fig. 2. Performance of operations in a wing box

ADVANCED METHODS FOR MANUFACTURING THE AIRCRAFT STRUCTURES USING INTEGRATED COMPUTER TECHNOLOGY

The development of modern aviation industry is characterized by escalated competition in world markets, which forces the corporations to ensure high-quality products and saving of resources (material, intellectual, and time ones) involved for implementing specific projects or programs at all stages of product life cycle.

The global market of high-tech products is evolving towards a transition to paperless technology of design, manufacture, and marketing of products. It is tending towards ensuring the manufacture of quality products at the lowest cost of labor and resources, in due time and in required quantity.

The necessary measures for reducing the time of preproduction engineering are as follows:

- Use of standard software for computer-aided design of technological processes (CAD);
- Development and implementation of more effective processes for design, manufacture, and installation of industrial equipment (including CAD of facilities and use of CNC devices);
- Simplification of assembly tooling design through the use of methods for assembly based on alignment and location holes and the use of efficient schemes of assembly for out-of-assembly-shop works;
- Introduction of non-lofting methods to ensure interoperability (based on the mathematical modeling of aircraft aggregate geometric shape);
- Development of standards for typical aircraft parts and components of blank and assembly tooling;
- Design of model re-adjustable assembling jigs and test devices.

Integrated quality of air vehicles determined by the parameters of flight performance, resource, and economic performance indices depends largely on the technology and organization of manufacture. The assembly is considered to be one of the key elements of the aircraft manufacturing process. The assembly and installation works are characterized by ever-increasing sophistication, relatively low level of mechanization of operations, high labor input, low productivity, and, as a consequence, by high labor-output ratio and cost of production.

Currently, only massive operations of assembling process, such as: drilling and cutting of holes; fastening (riveting, bolting, screwing, nutting); welding operations, gluing (e.g., cellular structures), pressing, flaring and so on are mechanized and automated. Consequently, improvement of assembly technologies in aircraft building is extremely important, inasmuch as they play a decisive role in assuring the efficiency of aircraft manufacture.

The survey [2] of foreign technologies for the assembly of aircraft structures has identified the following features of the assembly and installation works:

- Transition to flexible portable systems of positioning of plant working bodies;
- Use of the readjusted assembly tooling instead of the special one;

- Use of flexible hybrid robots;
- Transition to electrically-powered working members of fastening systems.

Taking into account the results of [2] and trends in automated assembly, the designs of industrial robots and their possible use for assembling works have been analyzed. An example of the robot application is showed in Fig. 2.

The joint operation of equipment and robots [3] is achieved through a group control system. The difficulties of group control realization are related to programming, information exchange, and synchronization of operation of heterogeneous equipment constituting the complex.

The analysis of conveyor assembly in the automotive industry has been made. In the car-building, the method of assembly is chosen depending on the precision of relative position of working surfaces of the parts, as a result of the analysis of dimension chains [2], and taking into account the economic feasibility of working accuracy, the precision of equipment and tools, the experience in the design and the sample test results.

The fierce competition between the major aircraft manufacturers, *Airbus* and *Boeing*, required a cut of production costs and an increase in the speed of assembly. Therefore, in 2001, *Boeing* upgraded its manufacturing facilities and shifted to a conveyor assembly of aircraft when the plane is delivered from one team of workers to another using a moving assembly line, with accessories, tools, and equipment located along it. *Chkalov* Novosibirsk Aircraft Production Association, a member of *Sukhoi* holding is the first Russian aircraft plant to launch a similar conveyor assembly line [4].

As a result of analysis, it has been found that the conveyor assembly is a promising direction to optimize the assembly processes. However, as of today, only the aggregate and the final assembly operations can be done using a conveyor line.

In connection with the above, the promising assignments to be solved are raising the efficiency and reducing the time of manufacture due to the use of automated assembly and computer-integrated technologies of robotic systems.

CONCEPTION OF AUTOMATED ASSEMBLY OF AIRCRAFT STRUCTURES

As part of this research [2], an approach to the sub-structuring of the plane, at the preliminary and at the final stages, has been developed. At the preliminary stage, the sub-structuring is carried out taking into account the design features and works to be done by specialized teams, as well as the conditions for ensuring the best performance. The sub-structuring at the final stage is made allowing for the specific features of application of robotic systems to automated assembly.

The sub-structuring of aircraft airframe into the components is described by the following schemes that can be represented as a graph:

$$G^j = (A^j, C^j), \qquad (1)$$

where $A_i^j = \left(A_i^I, A_l^{II}, ..., A_k^{II}, A_l^{III}, ..., A_m^N\right)$ is a set of structure constituents.

The bow composition is as follows:

$$C^J \ni c_{i(j)} = \begin{cases} 1, \ if \ A_i^J \ni A_j^{J+1} \\ 0, \ otherwise \end{cases}, \qquad (2)$$

or

$$C^J \ni c_{j(i)} = \begin{cases} 1, if \ A_i^J \ni A_j^{J+1} \\ 0, \ otherwise \end{cases}. \qquad (3)$$

Accordingly, in the first case, graph describes the decomposition (sub-structuring) of object A into the constituting structural elements and its composition (aggregation). The connectivity of structural elements can be described using a vertex incidence matrix. Thus, for graph G = (A, C) one can obtain

$$\left\| c_{i(j)} \right\|_A = |A \times A| = \begin{array}{c} \begin{array}{cccc} a_1 & a_2 & \dots & a_n \end{array} \\ \begin{bmatrix} c_{1(1)} & c_{1(2)} & \dots & c_{1(n)} \\ c_{2(1)} & c_{2(2)} & \dots & c_{2(n)} \\ \dots & \dots & \dots & \dots \\ c_{n(1)} & c_{n(2)} & \dots & c_{n(n)} \end{bmatrix} \end{array} \begin{array}{c} a_1 \\ a_2 \\ \dots \\ a_n \end{array}. \qquad (4)$$

The structural properties of product are described as loops. The composition of loops of assembly element A is represented by set F(A), while the compositions of loops of its elements

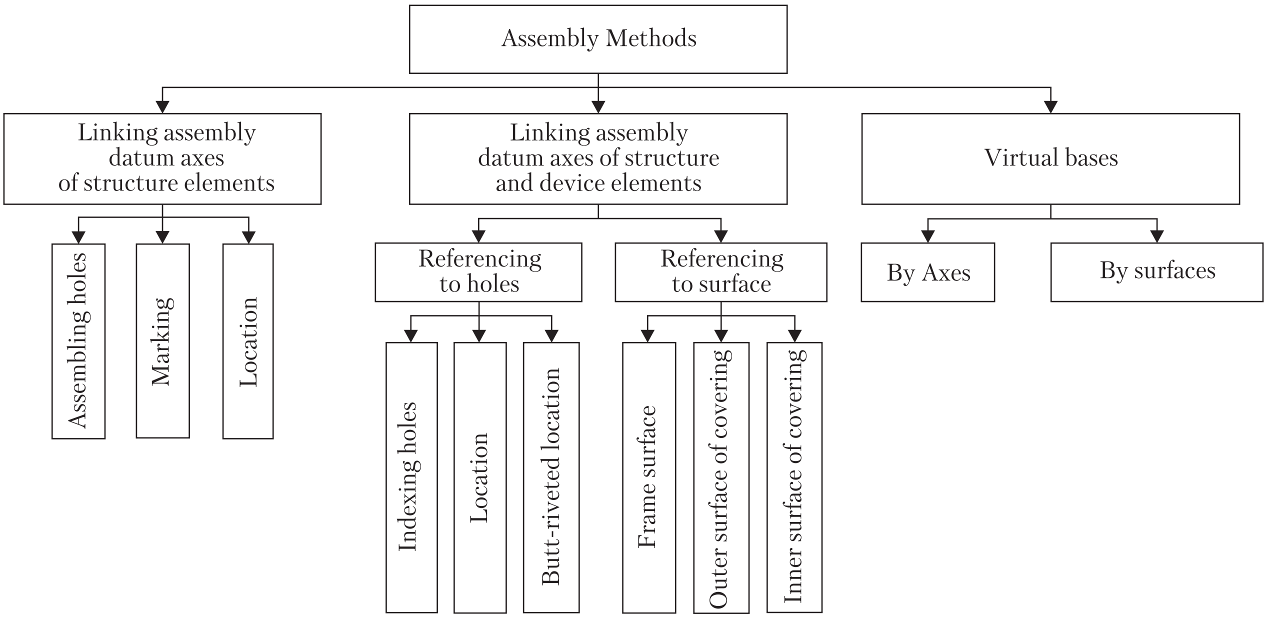

Fig. 3. Assembling methods used in the aircraft manufacture

correspond to sets $F(a_i) \subset F(A)$. The compositions of all loops of all elements can be described using a loop matrix:

$$\left\| c_{i(j)} \right\|_{A,F(A)} = |A \times A| = \begin{array}{c} \begin{matrix} F_1 & F_2 & \dots & F_m \end{matrix} \\ \begin{bmatrix} c_{1(1)} & c_{1(2)} & \dots & c_{1(m)} \\ c_{2(1)} & c_{2(2)} & \dots & c_{2(m)} \\ \dots & \dots & \dots & \dots \\ c_{n(1)} & c_{n(2)} & \dots & c_{n(m)} \end{bmatrix} \begin{matrix} a_1 \\ a_2 \\ \dots \\ a_n \end{matrix} \end{array}. \quad (5)$$

Here, $c_i(j) = 1$, if a_i has a loop F_j ($F_j \in F(a_i)$). Each loop F_i is characterized by a set of parameters M_i having certain numerical values. Required quality of the loop is known to be ensured only if for each parameter $m_j \in M_i$ the errors do not exceed the limits of tolerance band. Hence, the state of loop F_i can be determined by a variable:

$$F_i = \begin{cases} 1, \text{ if } \forall m_j \in M_i\ (\omega_j \subseteq \Delta_j) \\ 0, \text{ if } \exists m_j \in M_i\ (\omega_j \setminus \Delta_j) = \varnothing \end{cases}, \quad (6)$$

where ω_j is scattered error field of m_j parameter, Δ_j is tolerance band of m_j parameter.

The assembly elements are classified into units, panels, sections, cells, and aggregates. This approach enables the development of technological processes (TP) and automated sites for assembly of units and panels that have similar structural features. The application of automated and robotized assembly operations enables the design of new standard TP and assembly configurations for generalized complex assembly elements, as well as new means of linking. This reduces the pre-production time and is one of the most efficient ways to optimize the TP.

Obviously, the use of existing methods of assembly in the times of advanced computer technology and automated assembly is impractical, so a new method of assembly has been proposed. This is the virtual base assembly method [5].

The essence of this method is that the parts are positioned with respect to each other or relatively to the jig elements on the basis of electronic layout of assembly element using a robot manipulator (Fig. 3). For example, the virtual base assembly of units consists of the following operations:

1) Seizure of parts by robot and determination of their position (scanning and other methods for determining the size); after check, return of parts for improvement, if necessary;

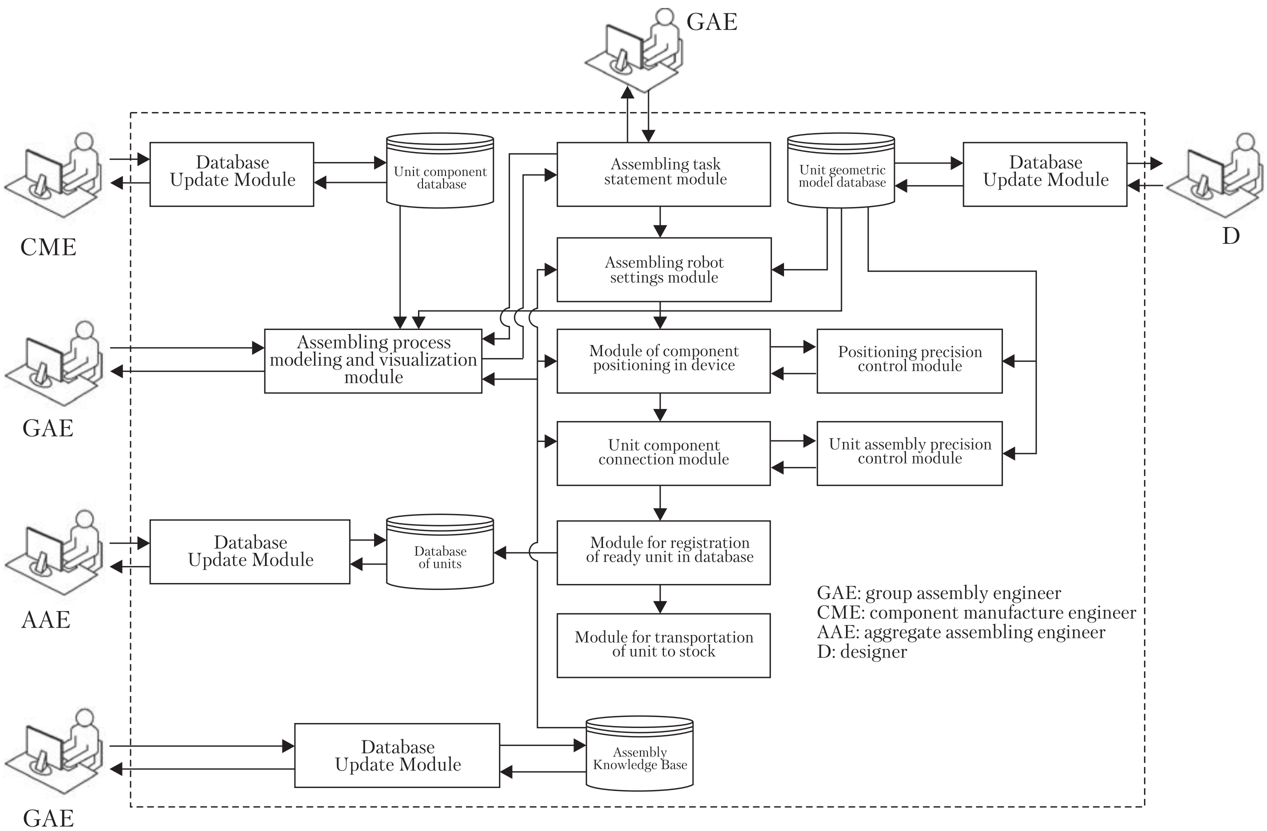

Fig. 4. Software structure

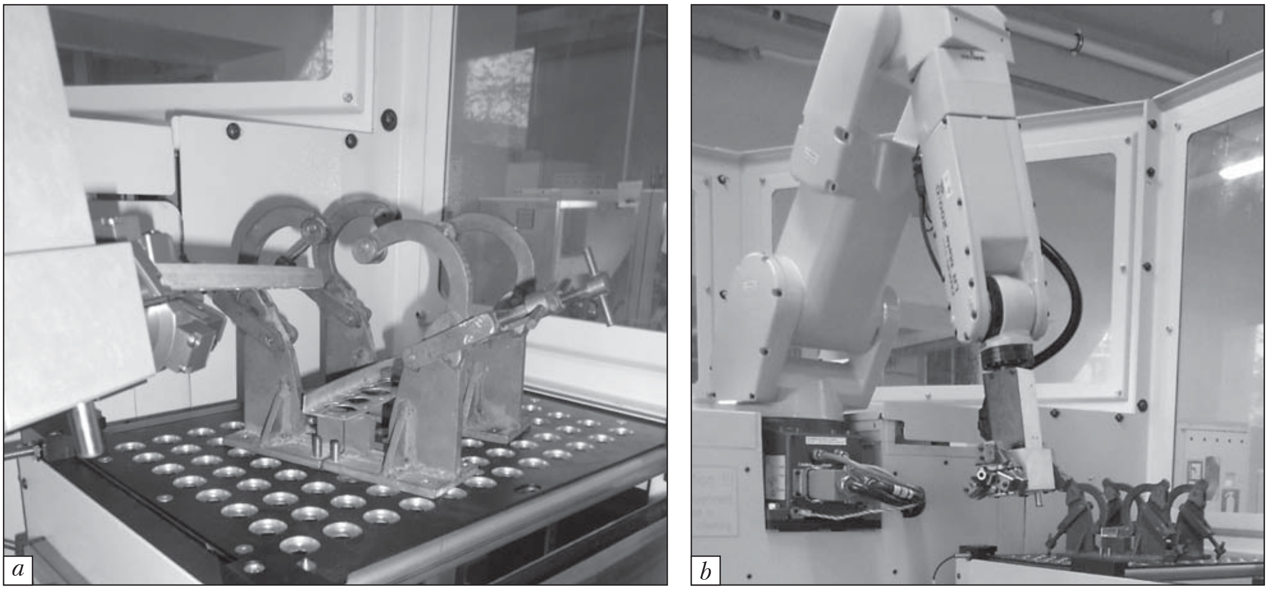

Fig. 5. Testing of software using *Fanuc LR Mate 200* robot: *a*) mounting of a rib; *b*) assembled unit (rib)

2) Installation of parts in the required position with respect to each other or to jig elements on the basis of electronic layout;

3) Fixing of parts in the assembly position;

4) Retaining of parts in assembly position;

5) Fastening of parts via riveting, bolting, welding, brazing, gluing, etc.

The parts to be installed are fixed either by means of special fasteners or kept by robot until they are connected.

In general terms, a typical process scheme of computerized conveyor assembly can be represented by equation

$$P = [УФ(a_{i_1}), УФ(a_{i_1}), C_{i_1 i_2}, ..., УФ(a_{i_{n-1}}), УФ(a_{i_n}), C_{i_{n-1} i_n}), В, У, К], \quad (7)$$

where P is manufacturing process; a_{i1}, a_{i2},... a_{in}, is sequence of installation of parts; $УФ$ is content of installation and fixation operations (lock release); C is content of connection operations; B is content of return operations; $У$ is content of retention operations; K is content of control operations.

In [2], a comparative analysis of the accuracy of unit assembly for different linking methods has been made. It has been estimated that the error of unit assembly using software and specialized re-adjustable CNC tools is less by about 64% as compared with the traditional method of linking.

EXPERIMENTAL STUDY OF ASSEMBLY PROCESS USING ROBOTIC SYSTEMS

On the basis of algorithms designed in [2] the software for visualization of the assembly process has been developed. The software structure is showed in Fig. 4.

In [6, 7], the architecture of software modules and the structure of data and information system have been considered; the possibility of applying the virtual base method of assembly to raise the efficiency of assembling the components of aircraft panels has been illustrated. Fragments of software application for assembly process visualization systems have been given; the software has been tested using a *Fanuc LR Mate 200* robot (Fig. 5).

To determine the total error of estimating the accuracy of the positioning of specialized re-adjustable CNC device the probabilistic and statistical methods are used, insofar as the error of re-adjustable CNC device depends on the errors of step motor, manufacture of retractable pins, linear and circular interpolation.

In [2], the accuracy of positioning of specialized re-adjustable CNC device has been estimated. As a result, it has been found that the device has a four-fold margin of accuracy for coordinated positioning of mounting elements.

CONCLUSIONS

1. Based on the analysis of trends in the development of advanced technologies of aircraft assembly, the areas of assembly automation and robotic application have been identified that enables the formation of the conception of aircraft automated assembly.

2. A method for virtual base assembly using specialized re-adjustable CNC devices and robotic systems for aircraft manufacture has been proposed; it enables automated assembly of aircraft structures.

3. An approach to automating the assembly site of aircraft manufacturer using robotic systems based on intelligent assembling robots, which ensures a stable assembly process has been proposed.

4. The software for visualization of automated assembly processes has been developed to enable a real-time control of automated assembly.

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СУЧАСНІ ПЕРСПЕКТИВИ РОЗВИТКУ ТЕХНОЛОГІЇ СКЛАДАННЯ АВІАЦІЙНИХ КОНСТРУКЦІЙ

На підставі виконаних теоретичних досліджень за допомогою методу віртуальними баз створено концепцію автоматизованого складання авіаційних конструкцій, спеціалізованих переналагоджуваних пристроїв з ЧПК та робототехнічних систем. Обґрунтовано принципи автоматизації складання літакобудівного підприємства з використанням робототехнічної системи

Ключові слова: автоматизоване складальне виробництво, робототехнічні системи, спеціалізовані переналагоджувані пристосування з числовим програмним керуванням, метод віртуальних баз.

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СОВРЕМЕННЫЕ ПЕРСПЕКТИВЫ РАЗВИТИЯ ТЕХНОЛОГИИ СБОРКИ АВИАЦИОННЫХ КОНСТРУКЦИЙ

На основе выполненных теоретических исследований с помощью метода виртуальных баз создана концепция автоматизированной сборки авиационных конструкций, специализированных переналаживаемых приспособлений с числовым программным управлением, а также робототехнических систем. Обоснованы принципы автоматизации сборки самолетостроительного предприятия с использованием робототехнической системы.

Ключевые слова: автоматизированное сборочное производство, робототехнические системы, специализируемые переналаживаемые приспособления с числовым программным управлением, метод виртуальных баз.

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