Positioning automation when assembling panel structures

M V Kovalevich and E S Shemonaeva
Moscow Aviation Institute (National Research University), 4, Volokolamskoe highway, Moscow, 125993, Russia
E-mail: kovalevichmv@mai.ru

Abstract. The article discusses the process of assembling low-stiffness panel structures typical of the aerospace industry. Due to the low stiffness of the incoming elements, the assembly of such structures differs from the assembly of structures typical of general mechanical engineering. To switch to a robotic assembly of such structures, it is necessary to comply with special requirements both to the technology and to the design of the elements included in the assembly. The paper investigates the process of positioning automation during the assembly of panel structures using industrial robots. The article describes a method of verification calculation for accuracy, which allows establishing whether the proposed positioning method meets the specified requirements for the aerodynamic contour of the product. Requirements for structural elements have been formulated, which will allow positioning during assembly with the required accuracy. The results obtained in the course of the study can be used in the design of new structures, the assembly of which will be carried out using automation tools. In addition, the developed requirements must be taken into account when switching to new assembly technologies for existing structures. The results of the study can help to improve the efficiency of assembly of flexible structures used in the aerospace industry. It was also found that it is necessary to conduct further research in terms of the influence of deflections of the structure from its own weight and during the supply of the tool that performs the setting of joints.

1. Introduction
Today, industrial robots are widely used in assembly operations in mechanical engineering. Many mechanical engineering products are classified as structures of high rigidity, which have pronounced assembly bases on the elements of mating parts during assembly.

However, there are also such designs that are characterized by insufficient independent rigidity of the incoming elements. For example, these include panel structures that are common in the aerospace industry. Such structures acquire the required rigidity after the establishment of power relationships - installation of fasteners. Thin-walled, lightweight panel structures, as a rule, are not self-sufficient in terms of basing. Therefore, they are collected in special assembly devices, which are, first of all, a source of additional bases [1, 2].

Assembly devices are characterized by a high cost due to high metal consumption, extremely high requirements for manufacturing accuracy with large dimensions, as well as their narrow specialization. Modern aircraft technology is aimed at simplifying the design and reducing the number of special assembly tooling.

The transition to robotic assembly of aircraft structures [3-8] imposes special requirements both on technology and on the design of the elements included in the assembly.
2. Formulation of the problem
Currently, the measurement-assisted assembly and its various variations are actively developing in the world [4-8]. The essence of the method lies in the positioning of the assembled elements using automation and under the control of measuring systems and, then, in keeping them in a given position during the process of making connections, as shown in Figures 1 and 2. Automatically controlled columns are used as positioners. A more flexible, but also more complex, scheme seems to be where industrial robots are used as positioners.

The positioning process is a complex problem associated with the problems of ensuring the accuracy of a given aerodynamic contour and the rigidity of structural elements.

Features of a measurement-assisted assembly using robotics are as follows.
1. It is necessary to pre-assemble the panels in a simplified assembly device - a pallet. The same pallet is used to position the panel in subsequent assembly steps.
2. The positioning accuracy of an industrial manipulator will not allow obtaining the accuracy required in the design of aviation technology. In this regard, the position of the robot is corrected using a laser tracker. In this case, the coordinates must be taken directly from the panel.

![Figure 1. Collaborative panel positioning](image1)

![Figure 2. Automatic panel positioning](image2)

3. Calculation methods
Reasoning from theoretical premises, the main consequence of nanopowder introduction into the melt should be refinement of the macro- and microstructure, as the powder particles must serve as nuclei of new grains. Figures 1 and 2 show photos of the microstructure of cast samples from the bronze of the lead-tin bronze grade, both modified by SDP of aluminium oxide and without modifier addition. The phase composition of the bronze under study represented in photos of the microstructure is a solid solution of tin in copper, lead inclusions and eutectoid inclusions based on electron compound. The ability to meet high requirements is determined by a verification calculation for accuracy.
The task of calculating the accuracy at the current stage is to determine the expected deviation from the theoretical contour at an arbitrary point of the side panel of aircraft.

The error of the functional size $\omega_L$ is determined [1]:

\[ \omega_L = \Delta_L \pm K_1 (1 + K_2 + K_3) \frac{\delta_L}{2} \]  
\[ \Delta_L = \sum_{i=1}^{m-1} \Delta_i \]  
\[ \Delta_i = BO_i - HO_i \]  
\[ \frac{\delta_L}{2} = \sqrt{\frac{\sum_{i=1}^{m-1} (\delta_i)^2}{2}} \]  
\[ \frac{\delta_i}{2} = \frac{BO_i + HO_i}{2} \]

where $K_1$ is the risk coefficient; $K_2$ - coefficient that takes into account the error caused by deformation when making connections; $K_3$ - a coefficient that takes into account the additional error that occurs when fixing elements; $\Delta_L$ - middle of the tolerance range; $\Delta_i$ - middle of the tolerance zone at each stage of the transfer of dimensions; $BO_i$ and $HO_i$ - upper and lower deviation at each stage of size transfer; $\frac{\delta_L}{2}$ - standard deviation; $\frac{\delta_i}{2}$ - standard deviation at each stage of size transfer.

The calculation results can be formatted graphically in the form of an image of the tolerance field shown in Figure 3.

\[ \Delta_L \]  
\[ BO \]  
\[ 0 \]  
\[ HO \]

**Figure 3.** Tolerance field with the location of deviations

For the task at hand, we take the following values of the coefficients: $K_1 = 2.37$, $K_2 = 0.3$, $K_3 = 0.3$.

When assembling by this method, there are some imprecisions associated with the assembly process, as well as with the transfer of dimensions from the electronic model to the product. The sources of these imprecisions with their values are shown in Table 1.

As a result of calculating the final imprecision, the expected deviation from the theoretical contour is ±1.32 mm.
Table 1. Imprecisions arising from the assembly by the coordinate-positional method

| Priority | Dimension transfer stage                                      | Dimension transfer imprecision \((BO, HO)\), mm |
|----------|----------------------------------------------------------------|-----------------------------------------------|
| 1        | Positioning by industrial robot                               | ±0.1                                         |
| 2        | Measurements with a laser tracker                             | ±0.05                                        |
| 3        | Deformation of the structure under its own weight             | ±0.3                                         |

4. Development of basic design requirements

Implementation of technology for existing structures entails reworking structures or designing new structures. In this regard, it is necessary to define and formulate requirements for constructions, the fulfillment of which will allow the effective application of a measurement-assisted assembly.

The requirements can be divided into two groups: for the basing process and for the joining process.

4.1. Requirements for the construction basing process

The requirements group determines the conditions that must be provided for in the design for the implementation of basing during assembly.

4.1.1. Weight of the structure. Restrictions on the weight of the product structure are imposed by the carrying capacity of an industrial robotic arm. The weight of the transition frame between the structure and the industrial robot must be taken into account.

We consider an aircraft in which the masses of the left and right side panels, taking into account the frame elements, are approximately 85 kg and 65 kg, respectively. The weight of the top panel with frame elements is 100 kg. Frame weight is approximately 80 kg. The weight of the attachments is 100 kg. The assessment of the lifting capacity of industrial manipulators was carried out on the basis of an analysis of the characteristics of the KUKA KR 1000 Titan robot. The maximum load capacity of this industrial robot is 1300 kg for palletizing operations. When holding the load in a certain position, the carrying capacity of the robot is estimated at 1000 kg. Thus, this value sets the weight limits.

4.1.2. Weight of the structure. The presence of platforms for the laser reflector. Determination and correction of the position of the panel in space is carried out using measurements performed by a laser tracker. To eliminate the influence on the accuracy of the panel positioning of errors associated with the adapter frame, the reflectors of the laser tracker must be installed directly on the panel. For this, the panel design must provide for appropriate places for their installation.

4.1.3. The rigidity of the structure. In general, the requirement is similar to the structural rigidity requirements for pre-assembly in an assembly fixture. Low stiffness can primarily affect the accuracy of mating contours in the joint zones. A diagram of the influence of deflection on positioning accuracy is shown in Figure 4.
4.2. Requirements for process jointed with industrial manipulators

The requirements group that must be provided for in the design to make joint during assembly.

4.2.1. The use of special fasteners in the structure of the unit. To implement the assembly method, special one-sided fasteners are required. Fasteners must be more durable than existing core rivets.

4.2.2. Approaches to the places of connections. The location of the seams should not interfere with the supply and movement of the multifunctional riveting head used in automatic riveting. A general view of the currently most common KUKA multifunctional head is shown in Figure 5.

4.2.3. The rigidity of the unit joints. The connection is made at a local power load from the equipment on the structure of the compartment. The rigidity of the structure at the place where the connection is made must be sufficient so that deformation from loads does not interfere with the quality of the connection. The initial data for the calculation are the load from the supplied tool and the permissible deformation. A diagram of the occurrence of a deflection in the area of the connection is shown in Figure 6.

Figure 4. Scheme of deflection influence on positioning accuracy: $\delta$ - deformation; $P$ - weight of the panel area

Figure 5. General view of the KUKA multifunctional head
5. Conclusion
As a result of the studies carried out, it was found that in order to achieve the required accuracy with the automated assembly of structures of low rigidity, it is necessary to comply with a number of requirements.

- The mass of the structure, including assembly equipment, should not exceed the lifting capacity of an industrial robot.
- The design of the product to be assembled must provide for areas for the installation of reflectors for laser measuring devices.
- The rigidity of the structure must be sufficient and exclude the deflection of the structure under its own weight.
- Using specialized one-sided fasteners.
- Open approaches for an industrial robot to the joints.
- The rigidity of the joints of the structure must be sufficient and exclude the deflection of the structure from the supply of the tool.

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