Method of designing robotic complexes with relative manipulation modules

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Abstract. The paper offers a method for designing robotic complexes with six degrees of freedom for processing complex parts containing a base and a module for installing tools and a module for processing parts placed on it, made in the form of parallel structure mechanisms, using CAD/CAM/CAE of the NX system under the control of the Teamcenter PLM system. Based on the terms of reference and draft documentation, a preliminary composition of the complex for components of the upper level of the assembly was developed. The stages of designing an electronic-digital model of a robotic complex are presented. A fully parameterized control structure was developed, which is the basis for building robotic complexes of various classes. The use of this approach allows the designer to reduce the complexity of designing similar complexes and simplify the process of making changes, as all changes are made to one part of the product, which has many versions. The application of the developed design methodology for various versions of robotic systems is shown. An algorithm for strength calculation of the assembly is presented. It is shown that the most effective result can be achieved only by using a combined design and calculation methodology.

1. Introduction

Currently, due to the increasing complexity and cost of technical devices, as well as more stringent customer requirements for the quality of the designed product, modern computer-aided design systems are increasingly used, which allow designing high-tech, competitive products, minimizing the cost of purchasing materials, manufacturing and testing [1-3]. The NX CAD/CAM/CAE system, which works in integration mode with the Teamcenter PLM system, is widely used for design and development work [4].

2. Materials and methods

CAD/CAM / CAE-NX system is a computer-aided design system that has a large set of tools designed for performing design and technological preparation of production, as well as conducting engineering analysis of designed products. The NX CAD/CAM/CAE system achieves maximum efficiency when running the Teamcenter PLM system, which unites all participants in the product lifecycle from the moment the idea of a future product appears to its disposal, thereby reducing the time to market for a new product and the final cost, as well as improving its quality. NX is widely used in industries that produce products with a high density of layout, a large number of parts and produce products with complex shapes, including in the mechanical engineering production of robotic systems.
This paper discusses an approach to the design of robotic complexes of a robotic complex with the possibility of relative manipulation of the part and tool along six coordinates during the processing of complex parts (Fig. 1). The mechanism contains a module for installing the tool and a module for installing the processed part based on parallel structure mechanisms [5-10].

Figure 1. Robotic complex: 1 – The upper module for tool installation; 2 – Base frame; 3 – The lower module for installation details.

The use of such mechanisms will increase the technical and operational efficiency of devices for manipulating space in six coordinates. An important advantage of this complex is the lack of dynamic coupling of drives, which complicates the control task.

3. Results and discussion
Based on the terms of reference and draft documentation, the preliminary composition of the robotic complex is being developed.

The upper level of the robotic complex assembly includes such components as the lower module, the upper module, and the frame.

Then the product composition is formed in the “structure manager” application of the Teamcenter PLM system. The Teamcenter structure manager application allows creating a single product structure, making changes to it, and managing variant build conditions. They can only work with object revisions in the structure manager.

It is very important to understand that depending on the level of entry of products into the assembly, the complexity of the design depends. A well-formed composition of both the assembly units and the main assembly makes it easy to manage the parameters of the future product.

The process of designing an electronic-digital model can be presented in a simplified form by the following stages (Fig. 2): building a control structure, preliminary design, development of an electronic-digital model, checking the correctness of assembly constructions, strength calculation of the structure, design optimization, and release of design documentation.

Figure 2. A simplified scheme of the design process.
The “Top-down” method is used in the design process [11]. This choice is justified by the fact that the geometry of most elements is completely unknown, and only their location in space is known. To facilitate the design process in accordance with the product composition, a control structure was developed (Fig. 3). The presence of a control structure in the assembly reduces the time for creating a model and provides the opportunity to work together on the product. A control structure is a set of different coordinate elements that occupy a certain position in the workspace. It is used for building geometry in the planes of the control structure, as well as for interfacing with assembly components. At the same time, according to the draft design, the planes are placed in the places where the main elements of the structure meet. The planes that limit the width of the frame are located relative to each other at a distance \( d \), the plane of the desktop is raised from the plane of the base to a height \( a \). The distance between the base plane and the top plane of the frame is \( H \). The plane of the working table is located at a distance \( b \) from the upper plane of the frame. The values of parameters \( a \), \( b \), \( d \), and \( H \) are set using the expressions command in the Modeling application. Figure 4 shows the parameters set for the robotic system.

**Figure 3.** Control structure.  
**Figure 4.** Dialog box “Expressions”.

When the control structure is built, a preliminary design process is carried out, during which the required configuration of the robotic complex is determined. Also, by setting the location of coordinate elements of the control structure through variables, they can create a fully parameterized control structure, which is the basis for building robotic complexes of various classes.

This approach makes it possible to manage the variant composition of the product, which can have a large number of different versions that are simultaneously in production and can be delivered to the customer. The use of this approach allows the designer to reduce the complexity of designing similar complexes and simplify the process of making changes, as all changes are made to one part of the product, which has many versions.

For example, if the customer needs to process large-sized parts relative to the vertical axis, in the “Structure Manager” application, a version of the robotic complex with an increased frame height can be selected (Fig. 5), or, if the customer does not need 5-coordinate processing of products, then you can make the active version of the product composition, in which the desktop is statically fixed (Fig.6).
In addition, this robotic system can have a version with a modification for the possibility of its use in the field of additive manufacturing (Fig. 7) due to its characteristics, which include high accuracy, speed of movement of the upper platform. Variants of a robotic complex with a completely different kinematic scheme of the device can also be developed (Fig. 8).

After the required configuration of the robotic system has been selected, a rational profile is selected from which the frame should be made. For design reasons, the selected profile must provide the necessary strength, rigidity of the finished product and manufacturability of assembly with minimal time.

The next step is to build an electronic-digital model of the robotic complex in the NX CAD/CAM/CAE system.

The frame is constructed using a control structure, with reference to the base planes, the upper plane of the frame, and the planes that limit the width. When the frame of the robotic system is ready, they need to create the geometry of the desktop located in the assembly of the “Lower module”.

This is followed by building level 2 assemblies, in particular the upper and lower modules. A sketch is created in the desktop plane, and then the “Pull” command creates a geometric model of the table. The next step is to fix the geometric model of the desktop for easy construction and positioning of subsequent components of the assembly relative to the main part. The rest of the assembly components are built in the same way. Figure 9 shows the completed model of the lower module.

Then the rest of the components are completed and the correct construction of the robotic complex assembly is checked, i.e. the gap analysis is performed. This command allows setting whether the geometry of the assembly components intersects with each other. If there is intersection geometry,
then the geometry of these components is either changed if it is an intersection between parts or subassemblies, or intersections are added to exceptions if it is an intersection geometry in threaded connections.

The other models in the assembly are also positioned relative to the control structure and the existing geometry. Figure 10 shows the completed model of the robotic complex.

![Figure 9. 2 ready build level.](image1)

![Figure 10. Electronic-digital model of a robotic complex.](image2)

The next stage of designing a robotic complex is the strength calculation of the assembly, the stages of which are presented in a simplified form in Fig. 11.

![Figure 11. Algorithm for strength calculation of the assembly.](image3)
1) Select the assembly for which they want to perform the strength calculation.

2) Creating FEM assembly and FEM parts files.

3) The purpose of the materials. Materials are assigned to each part, this is necessary in order to correctly calculate the weight of the nodes that rest on the frame.

4) Creating a grid collector.

5) Creating a grid. At this stage, a 3D finite element grid is created. Creating a finite element model is a key step in the preprocessor, as the accuracy of the results depends on the quality of the finite element grid.

6) Creating a simulation file.

7) Setting boundary conditions. At this stage, all unconnected 3D solid-state finite elements are connected to a single finite element model using the “Surface-to-surface bonding” command. This is necessary to describe correctly the interaction of structural elements. After that, loads are applied to the frame elements. The weight of the lower and upper modules is applied as the load. The load from the weight of the upper module is applied to the middle sections of the finite element grid obtained when dividing the body of the upper profile model using the “Force” command with the selected “Total per object” distribution method. Gravity must also be taken into account. The “gravity” command takes into account the self-weight of the frame structure. As the frame is based on the lower faces of the “Lower Profile” pipes, they are fixed using the “Seal” command. This command denies the selected objects six degrees of freedom.

8) Solution. The obtained results during the solution are located in the postprocessor Navigator.

9) Analysis of the results obtained. In order to obtain a conclusion about the performance of the structure under the imposed restrictions and loads, it is necessary to check the conditions of strength and rigidity of the product. To do this, the load-bearing capacity of the frame is evaluated using the criteria of plasticity (fluidity).

10) If the strength conditions are met, the design documentation is issued; if not, the calculated design is optimized.

4. Summary
Thus, having studied past achievements in the field of design and calculation of robotic systems, we can say that the most effective result can be achieved only by using the design and calculation methods together. Using this method, they can develop a variety of variants of structures of this class, depending on the customer’s requirements, with minimal time spent.

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