Digital design of a cable-driven parallel robot

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Abstract. The paper analyzes various computer-aided design systems. It is shown that the use of CAD / CAM / CAE-system NX allows to reduce the cost of the final product, increase the level of quality, and reduce the time to market. The article discusses the digital design of a cable-driven parallel robot (CDPR) for various applications using the NX CAD / CAM / CAE system. The mechanism is a rigidly fixed frame connected through tensioned cables to a platform. CDPRs have such advantages as a large working area, ease of assembly and disassembly, high mobility, large lifting capacity, and reconfiguration. The kinematic diagram of the device is presented. Based on the terms of reference and sketch documentation, a preliminary composition of the CDPR has been developed. During the design, the Top-Down method was used. The characteristics are analyzed, and the workspace of the mechanism is formed, taking into account the factors of limitation. Shown is a detailed design of the basic structure of a CDPR with an indication of the main operations. An electronic-digital model of the basic structure of a CDPR, which will later be used for kinematic and static calculations, as well as for making an experimental sample, is presented.

1. Introduction

Computer-aided design systems that solve a wide range of engineering problems have become widespread for completely new designs developing of equipment [1-3]. There are many digital design software on the market that have their features. The leading suppliers in the market of such software are Dassault Systems with their products with CAD / CAM / CAE-system CATIA and CAD / CAE-system SolidWorks, Siemens PLM Software with CAD / CAM / CAE-system NX and CAD / CAE-system Solid Edge, and Top Systems with CAD / CAM / CAE-system T-Flex.

But despite such a wide range of design software, one of the best can be considered the CAD / CAM / CAE-system NX, which provides an integrated solution for digital design, technological preparation of both additive and traditional manufacturing, and engineering analysis of mechanical systems, possessing powerful functionality for the development of competitive products.

NX CAD / CAM / CAE system allows to achieve your goal with maximum efficiency, reduce the cost of the final product, increase the level of quality and shorten its time to market. At the same time, the NX CAD / CAM / CAE system provides the user with a fully integrated manufacturing solution covering all stages, such as: part design, topological optimization of model geometry, model adaptation, analysis and verification of geometry for strength, production preparation, data and process management.
Consider the application of the NX CAD / CAM / CAE system for the digital design of a cable-driven parallel robot (CDPR).

2. Materials and methods

CDPRs are a special type of kinematic structure, consisting mainly of a working tool connected to a fixed base platform using cables [4-9]. Conventional CDPRs are composed of three parts, including a fixed platform, a mobile platform, and multiple cables that are used to connect the fixed platform and the mobile platform. The cable length can be changed through winches powered by motors mounted on a fixed platform.

One of the disadvantages of classic parallel robots is their limited workspace, mainly due to the limited travel of linear actuators and their accuracy. In CDPRs, this problem is solved by replacing the actuators with cables. In addition, CDPRs have such advantages as a large working area, easy assembly and disassembly, high mobility, large lifting capacity and easy reconfiguration. By controlling the length of the cables over a wide range, you can get access to a very large workspace from several tens of centimeters to several tens of meters or more. The use of cables instead of rigid links further reduces weight since the actuators do not change position and are fixed to a fixed base so that the only moving parts are the cables and the output link. As a result, a robot is obtained with higher speed and maneuverability and increased load capacity. The production costs of CDPRs are significantly lower than those of conventional manipulators. CDPRs are easy to install. Such a manipulator can be assembled using a number of inexpensive winches and cables. Also, since the motors do not need to be installed close to a moving platform, they are suitable for use in hazardous environments. Also, their lifting capacity is relatively high, even comparable to construction cranes.

The kinematic structure of the robot is shown in Fig. 1. The CDPR is designed to move loads in special conditions and contains four electric motors 1, 2, 3, 4, each of which includes a device for laying cables and a gearbox. Electric motors are driven into rotation by control device 5. Gearboxes of electric motors 1, 2, 3, 4 are connected to cables 6, 7, 8, 9 to move the load in the horizontal plane, respectively, through rollers 10, 11, 12, 13. Rollers 10, 11, 12, 13, are located on the frame 14. The output link is a movable platform 15 connected to the cables 6, 7, 8, 9.

The CDPR works as follows. When the electric motors 1, 2, 3, 4 rotate, with devices for laying cables and gearboxes, the angular position of the shafts of which is set by the control device 5, the length of the cables 6, 7, 8, 9, supported by rollers 10, 11, 12, 13, changes, located on the frame 14, as a result of which the gripper moves to the desired point in space. In this case, it is assumed that the cables 6, 7, 8, 9 are capable of moving the gripper due to the output link, which is attached to the platform 15.

![Kinematic diagram of a CDPR](image)
3. Results and discussion
The composition of the CDPR was developed on the basis of the technical task and sketch documentation for the design and construction work, as well as for the kinematic and static calculation.

The Top-Down method was used during the design [10]. The composition of the product was formed in the NX CAD / CAM / CAE system to facilitate the work. First, the geometry of the frame model is created. The frame consists of several elements: vertical post, lower profile, upper profile. Frame design starts with bottom profile.

A section of the profile is drawn using the "Sketch" command. We begin to draw one of the parts of this profile. The sketch is completely limited after mirroring the remaining parts (Fig. 2).

![Figure 2. Sketch of the profile of the vertical post.](image)

A solid is drawn using the Extrude command when the profile sketch is ready (Figure 3). The last action is to round off the edges using the "Rounding edges" command (Fig. 4).

![Figure 3. Constructing the geometry of the vertical rack.](image)  ![Figure 4. Rounding edges.](image)

The remaining frame elements are completed after building the lower profile. A model of the frame assembly is assembled using the commands located on the "Assemblies" toolbar (Fig. 5). In product design, you mate major assembly components using the "Mates" command.
Then we build plates (Fig. 6) and attach them at the junction of the profiles that make up the frame. The next step is to build plates (Fig. 7) on which the motor, winch, pulleys, etc. will then be located.

After all the components are built, fasteners are added to the frame assembly. We also model the corners (Fig. 8), in which bushings, couplings, pulleys, and coils will then be attached. After that, a motor of a standard size is built according to GOST (Fig. 9).
The next step is to build bushings, couplings, bearings (the zz marking in the bearing means that it is closed on both sides by metal membranes).

Then we build shafts, pins and coils for the cable (1 layer of cable with a diameter of 1.2 mm is placed on the smallest coil, 1.6 m of the same cable should be placed on a coil of larger diameter) (Fig. 10-13).

![Figure 10. Fastening shafts in bearings.](image1)

![Figure 11. Fastening the studs.](image2)

![Figure 12. Fastening cable spools.](image3)

![Figure 13. Fastening the pulleys.](image4)

After all the components are built, fasteners (bolts, nuts) are added to the frame assembly (Fig. 14).

![Figure 14. Fastening the bolts.](image5)

Fig. 15 shows an electronic digital model of the basic structure of a CDPR for various applications. This model can be applied to various options for cables and grippers, depending on the task and environment of the robot.
Commercial and standard products dominate the assembly of the CDPR, but some of the parts, such as bushings, reels, pulleys, and corners, will be made by one of the types of additive technologies used in various industries. The use of additive technologies in the manufacture of a CDPR will allow solving the problem of rapid prototyping of a complex mechanical system, which in turn can reduce the time spent on manufacturing and repairing a product and reduce the time for evaluating the physical model of the robot. Fast and cheap production of parts using additive technologies can significantly increase the competitiveness of new products on the market.

4. Summary

Thus, the CAD / CAM / CAE-system NX application allows you to design new products in the shortest possible time in a single environment. The resulting digital models of products are subsequently improved to create an optionally selectable range of products. This approach allows us to consider the wishes of all consumers of the market of robotic systems who need geometric shapes, colors, sizes of products, and materials from which they are made.

In the future, it is planned to carry out kinematic and static calculations based on the draft design and the constructed digital model, as well as to manufacture an experimental sample of a CDPR.

5. References

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