The use of the digital twin in the design of a prefabricated product

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Abstract. This paper discusses the process of creating a digital twin of a product, which is a virtual model of a mechanical connection. The modeling was carried out using the Pro/ENGINEER software, which allows building a three-dimensional model of the product assembly process, which is a set of three-dimensional electronic models of the product, equipment and tools. The models include a mathematical description of the geometric, physical-mechanical and technical parameters of the objects under consideration. It is shown that it is the formation of a triad of electronic models: product-man-equipment in the considered area of computer-aided design of technological processes for the implementation of mechanical connections that allows modeling with the necessary accuracy and adequacy.

1 Introduction

The modern world, having gone through three industrial revolutions in its history, is faced with a new concept - "industrial revolution 4.0" (Industry 4.0), an innovation seen as the impending fourth industrial revolution. It was at this fourth stage that the concept of the so-called digital twins (Digital Twins) began to be actively used. This term appeared in the early 2000s, but every year, as industrial and computer technologies develop, it receives new content [1].

This concept was first fully described at the University of Michigan in 2002. Now the digital twin of a product is its virtual model, which at the micro and macro levels either describes a real-life object (acting as a duplicate of a finished specific product), or serves as a prototype of a future object. At the same time, any information that can be obtained when testing a physically existing product must also be obtained on the basis of testing its digital twin. The digital twin of a product is used at all stages of the product life cycle, including design, production, operation and disposal. A classification that includes three types of product twins is now widespread: digital twin prototypes (Digital Twin Prototype, DTP), digital twin instances (Digital Twin Instance, DTI) and aggregated twins (Digital Twin Aggregate, DTA) [2].

A DTP twin characterizes the product it is a prototype of and contains the information

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needed to describe and create physical versions of the product instances. This information includes geometric and structural models, technical requirements and conditions, cost model, calculation (design) and technological models of the product. The DTP twin can be considered a conditionally permanent virtual product model.

Item DTI twins describe a specific physical instance of an item family with which the twin remains associated throughout its lifetime. Twins of this type are created on the basis of a DTP twin and additionally contain production and operational models, which include the history of manufacturing the product, the applicability of materials and components, as well as statistics of failures, repairs, replacement of components and assemblies, etc. Thus, the DTI twin of the product is subjected to changes in accordance with changes in the physical instance during its operation.

DTA twins of a product are defined as an information management system for the physical instances of a product family that has access to all of their digital twins [3].

When designing modern prefabricated products, given the high density of assembly, one of the main problems is to provide access to individual units at all stages of its assembly or disassembly. In addition, the designer has to solve the issues of the sequence of installation and interconnection of the individual nodes that make up the product. It should be especially noted that the mistakes that can be made by the designer when solving the above tasks lead to the impossibility of assembling the finished product, which is usually found out at the stage of assembling the first sample of the product [4]. In order to eliminate such errors, at present, digital twins are widely used at the design stage. The digital twin of a product is understood as its virtual model, which at the micro and macro levels either describes a real-life object (acting as a duplicate of a finished specific product), or serves as a prototype of a future object. At the same time, any information that can be obtained when testing a physically existing product should also be obtained on the basis of testing its "digital twin" [5, 6].

The presented work considers a virtual model of a mechanical connection, which is a set of three-dimensional (volumetric) electronic models of a product, equipment and tool, as well as an electronic model of a person. Models should include a mathematical description of the geometric, physical, mechanical and technical parameters of the objects under consideration. It is the formation of a triad of electronic models: product-man-equipment in the considered field of computer-aided design of technological processes for performing mechanical connections that allows modeling with the necessary accuracy and adequacy.

2 Model and method

To date, there are a fairly large number of programs that allow you to simulate the technological processes of performing mechanical connections. The principle of operation of the programs is based on the fact that already at the design stage, a team of engineers using computer-aided design tools will be able to simulate the process of interaction between the future product and equipment, taking into account the physiological characteristics of the operator performing the technological operation [7]. Program data such as: Unigraphics, CREO, Pro/ENGINEER, CATIA, etc.

The use of electronic models of technological processes for making mechanical connections will be considered using the example of a stand for static tests of the inner flap of a civil aircraft (Fig. 1) [8].

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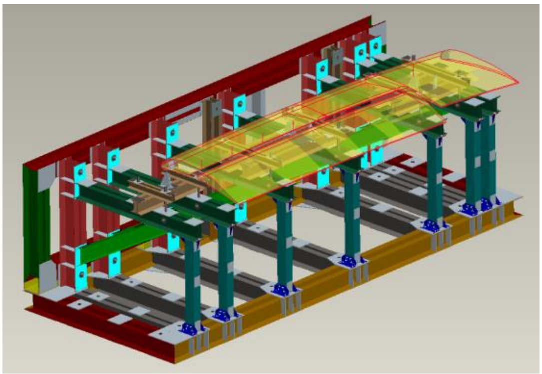

Fig. 1. Inner flap static test stand.

3 Research and results

To begin with, we will analyze the accessibility of the area for performing mechanical connections without the participation of the human factor.

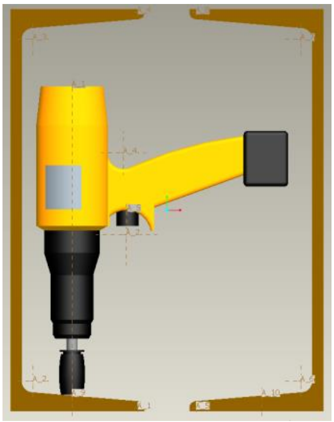

Fig. 2. Possible movements of technological equipment in the connection area.

The creation of electronic models of technological processes for performing mechanical connections allows solving the problem of determining the possibility of supplying technological equipment to the connection zone. Figure 2 illustrates well the case when the equipment can be placed in the connection zone, but it is impossible to bring this equipment to the place of the technological operation.

Consider the stages of creating electronic models of technological operations:

3.1 Creation of a three-dimensional electronic model of equipment (tool)

In the computer-aided design system, we create an electronic 3D model of equipment (tool) guided by the available documentation for the tool, where its overall parameters are specified [9]. Figure 3 shows the simulation result of an electric impact wrench.

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Fig. 3. Electronic 3D model of an electric wrench.

3.2 Creating a silhouette along the tool path

Let us assume that when the technological equipment (tool) moves, an imaginary trace remains. Accordingly, it is possible to create a model of a set of successive traces left with a certain step along the trajectory of the movement of the equipment (tool) (Fig. 4). It should be noted that the smaller the step between the traces, the more accurate the final result will be. It is necessary that the created tool trajectory (Fig. 5) be able to quickly and easily correct it in order to find its most optimal variant. To control the access of technological equipment to the area of mechanical connection, it is enough to place the considered set of consecutive traces in the working area along the created trajectory (as shown in Fig. 6) [10]. In the case of non-intersecting trace and product geometries, a decision is made on the possible use of this technological equipment (tool) in the considered technological operation. In the case of detection of intersection of the trace and product geometries, a decision is made on the unsuitability of this equipment (tool) for performing this mechanical connection or corrective changes are made to the product design [11]. But to what extent this imitation corresponds to reality, because in the considered case one of the most important factors is not taken into account - the characteristics and capabilities of the human body. For the reliability of the results, it was decided to supplement the modeling process with the human factor, namely, to create the interaction of an electronic 3D model of the tool execution area, an electronic 3D model of the tool in the aggregate with an electronic model of a person (parts of the human body) [12,13]. In this case under consideration, it is sufficient to use the electronic model of not the whole person, but only his hand. This will, in turn, make it possible to simplify the modeling of the considered process of making a bolted connection in the working area, since no need to spend time orienting the electronic model of the whole person in the virtual space [14,15].

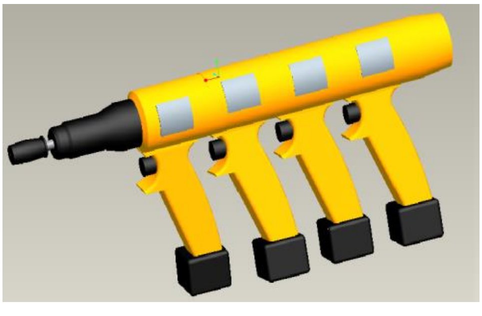

Fig. 4. A set of successive traces of the translational movement of the tool.

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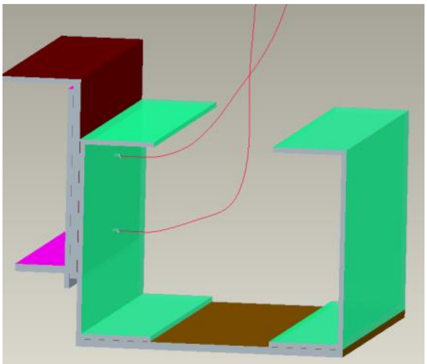

Fig. 5. Tool paths to the connection point.

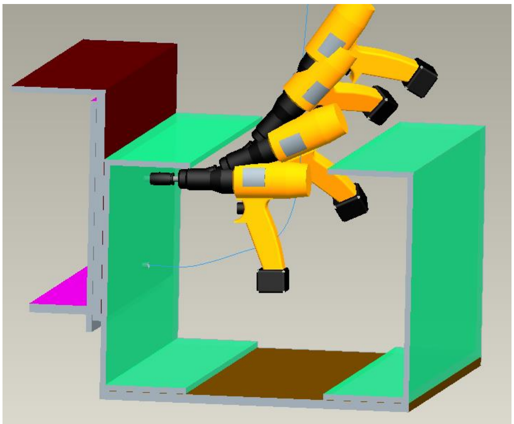

Fig. 6. Movement of the working tool along a given trajectory to the junction.

3.3 Simulation of an electronic model of a human hand

In the computer-aided design system, we create an electronic 3D model of a human hand (Fig. 7). There is no need to thoroughly duplicate all the characteristics of the human hand, it is enough to create a simplified electronic 3D model and put into its design only some qualities such as: the distance from the shoulder to the elbow, the size of the forearm, the size of the hand, the geometric parameters of the volume of the designed parts, it is also necessary to put into the electronic model mobility of the hand and elbow joint [16,17].

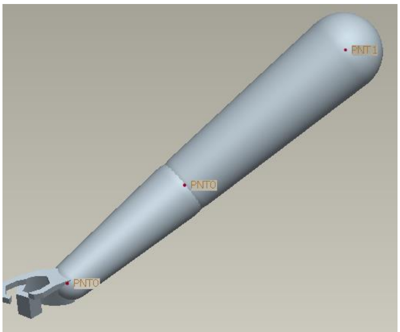

Fig. 7. Electronic 3D model of a human hand.

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3.4 Determination of the working position of the electronic model of the equipment (tool) and the electronic model of the human hand

Next, we create an assembly file, the components of which are previously created electronic models of equipment (tools) and human hands (Fig. 8). When assembling, it is necessary to fix these components in the same way as the equipment (tool) is located in the hand when performing a particular technological operation [18,19].

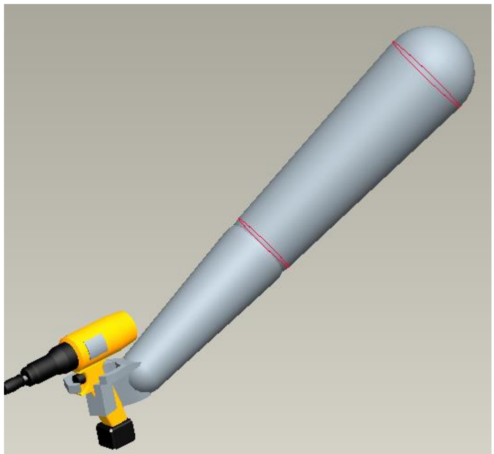

Fig. 8. Mutual orientation of electronic models of instrument and human hand.

After the completed operations to create an electronic 3D model of a human hand, we return to the analysis of the accessibility of the area for performing a mechanical connection. It can be seen that for the previously considered variant of the trajectory of the tool and its orientation in space is impossible, because there is a mutual mutual intersection of the electronic models of the connection execution zone and the human hand (Fig. 9) [20, 21].

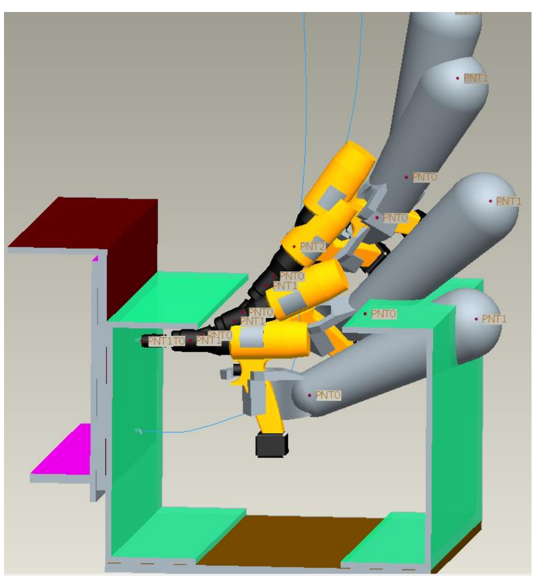

Fig. 9. Performing a mechanical connection taking into account the human factor.

We perform corrective actions of the tool that has received a trace of movement, taking into account the human factor (Fig. 10, 11, 12).

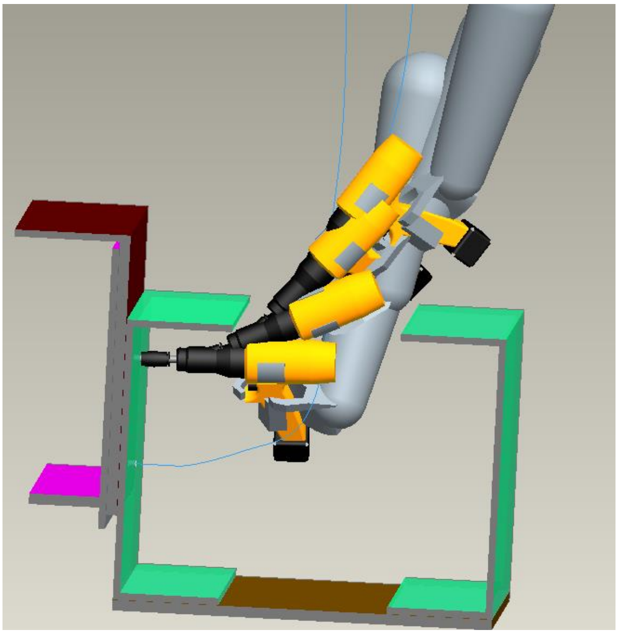

Fig. 10. Tool trace right side view.

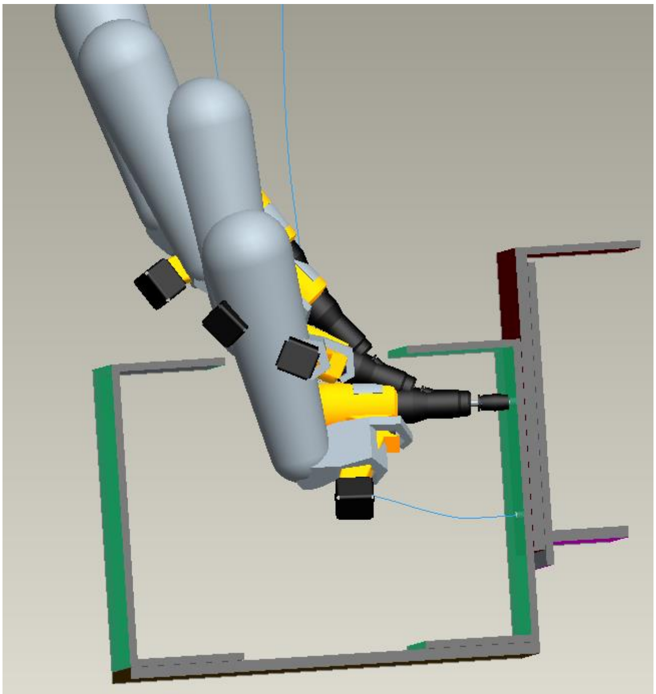

Fig. 11. Tool movement trace left view.

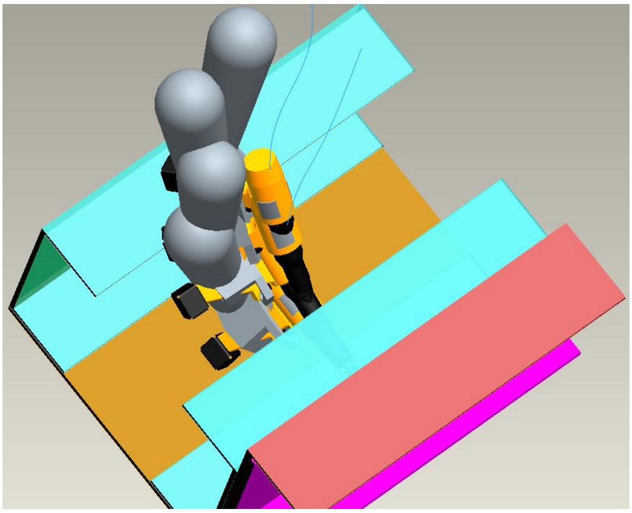

Fig. 12. Tool movement trace top view.

Conclusion

It has been established that in order to analyze the accessibility of the mechanical connection area, it is not enough to be guided only by electronic models of the product under study and equipment that is supposed to be used in the process under consideration, but it is also necessary to take into account the human factor.

The use of a triad of electronic 3D models "product-man-tool" gives the designer the opportunity to automatically control access to the equipment and tool connection zone, substituting ready-made electronic models of technological operations into the computer modeling process. Thus, the designer is able to quickly answer the question: is it possible to perform a mechanical connection? If yes, what equipment?

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