Application of the geometrical models, graphs and elements of robots kinematics as the basic elements of the unified methodology for assurance of accuracy calculating stage in precision axisymmetric products assembling

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Abstract. The accuracy standards of engineering products, namely geometric parameters, such as tolerances, geometry deviations and surfaces form deviations, are indicative of parts and assembly units quality. The article discusses the integrated approach to the study of accuracy parameters using geometrical models, graphs and elements of robots kinematics as the basic elements of the unified methodology for assurance of accuracy calculating stage in precision axisymmetric products assembling. The integrated approach is to combine the developed techniques into a unified methodology for assurance of accuracy calculating stage in precision axisymmetric products assembling. The implementation of this approach is carried out by a phased study of the construction for all accuracy parameters in a common reporting format based on key provisions Obtained results suggest quickly make changes to the studied design based on the phased analysis according with the developed integrated approach.

Keywords: geometrical models, graph, assembly process, dimensional parameters, geometry deviations.

1. Introduction

Process planning reveals a close relationship between design and manufacturing. It determines the manufacturing processes, their sequence and conditions for the project transformation into a physical component economically and competitively [1-6]. In the traditional approach, manufacturing professional employee were used, their experience and knowledge were applied to solve issues of process planning and served as a guide to how to produce products [7, 8]. Since the early 1960s, computers have been used to assist in the design, process planning and manufacturing activities because of their ability to perform complex functions quickly and accurately [1, 9].

Modelling of the assembly process is an important stage in product development and structural assembly, which is fundamental in the properties analysis and product design [10, 11]. Any project or exploratory activity in some extent related to the modelling [12]. A basis of modeling is the theory of similarity, however, in modeling practice to an absolute likeness do not tend, moreover, to attempt as fully as possible reflect the properties and characteristics of a complex object leads to the excessive growth of the models complexity, which significantly reduces its practical usefulness. In this work, geometric model of the parts are used, that carry the necessary information for analysis information [13, 14]. One of the most important indicators that determine the ability to perform intended service is the geometric accuracy. The level of accuracy of the performed assembly process and assembly unit depend on factors such as reliability, availability, efficiency, vibration and noise, quality and productiveness [15].
When modeling assembly technology, graph theory is used, which allows to connect theoretical positions with specific computational algorithms that are simply implemented on a computer. The founder of the use of mathematical models in the form of a graph in mechanical engineering is B.S. Mordvinov [16], who introduced the concept of the interconnected geometric structure of a machine and its graph. Bozhko A.N. applied a combinatorial hypergraph model to generate assembly sequences and product decomposition schemes into assembly units [17]. Artyushenko V.M. used the visualization method using three-dimensional modeling and additive technologies in the assembly and optimization calculations of engineering products [18]. Bahubalendruni R. developed a concatenation method for generating optimal sequences of a robotic assembly, proposed a method for extracting a mechanical feasibility matrix using algorithms as an example [19]. Das A. is developing an approach to the assembly transfer function to simulate the assembly process using imperfect parts that meet the requirements of [20]. Ghandi S., through two new taxonomies, defines and describes the properties and types of problems that arise during assembly and decomposition of products, as well as approaches to their solution [21].

In this paper, integrated approach to the study of accuracy parameters in relation to the assembly according to the developed techniques [22-25] is proposed.

2. Problem statement

The accuracy standards of engineering products, namely geometric parameters, such as tolerances, geometry deviations and surfaces form deviations, are indicative of parts and assembly units quality. In this paper, an integrated approach to the study of accuracy parameters is proposed. The key provisions for implementing an integrated approach in the study of axisymmetric products assembling are:

- Geometric models of parts – as a foundation for analysis and accuracy studies, because most accurately represent geometric information about geometry deviations and surfaces form deviations;
- Graph theory – as a connecting element of theoretical principles and computational algorithms;
- Elements of robots kinematics – used as a tool for linking the assembly under study to the coordinate system with subsequent visualization in Excel program, by adapting the mathematical apparatus used in the robots kinematics.

3. The developed theory

An integrated approach is to combine the developed techniques into a unified methodology for assurance of accuracy calculating stage in precision axisymmetric products assembling. The implementation of this approach is carried out by a phased study of the construction for all accuracy parameters in a common reporting format based on key provisions ‘Figure 1’.

Let us consider in more detail each of the presented techniques using the example of the assembly ‘Figure 2a’

To study accuracy parameters using an integrated approach, it is necessary, by converting all surfaces of parts to flat and cylindrical, to compose geometric models of the parts included in the assembly and
then a geometric model of the assembly ‘Figure 2b’. The resulting geometric models will be the initial data for further analysis. Next, pass on to the graph of the geometric model ‘Figure 2c’ by representing in the form of vertices of the graph details (circles with the position number), and in the form of edges of the graph, contacts and physical gaps (numbered segments between the vertices of the graph with the contact number). The sequential transition from the assembly drawing to the geometric model of the assembly and then to the graph of the geometric model is shown in ‘Figure 2’.

**Figure 2.** Initial data for dimensional analysis of construction. (a) assembly, (b) geometric model of the assembly, (c) graph of the geometric model.

The purpose of dimensional analysis of construction is to ensuring the products quality, selecting optimal accuracy, which provided the assembly efficiency, by determining, first of all: the dimensions and tolerances of the assembly (closing links of dimensional chains) and further: the dimensions and tolerances of the assembly parts (component links agreed upon for accuracy with the accuracy of the closing links). The technique for automated dimensional analysis of constructions [22] is presented in the ‘Figure 3’.
The program results are: 1) graphical visualization of the result, for which compliance needs to be assessed the obtained image to geometric model; 2) information file in which table for expected errors of the closing links and messages on failure to ensure of tolerances of the closing links are displayed. In the table of expected errors of the closing links, the following are displayed line by line: index of closing link, its tolerance, expected error, i.e. the tolerances sum of component links, and designations list of component links for corresponding dimensional chain.

The technique for automated dimensional analysis of constructions in its form boils down to a dialogue between the designer and the computer, in which the computer acts as an expert identifying errors, helping them to eliminate and evaluating each decision made in accordance with the main principles of the theory of dimensional chains and dimensional analysis.

Next, using the technique for automated assembly sequence determination [23], we are determining the assembly sequence, namely, forming the assembly diagram and the routing assembly technology process. At this stage, also are used the previously generated geometric model of assembly and graph of geometric model. When modelling assembly technology, graph theory is used, which allows to connect theoretical positions with specific computational algorithms that are simply implemented on a computer. This technique makes it possible to obtain automatic construction of assembly diagram and automated construction of construction model. ‘Figure 4’ presents: Technique for automated assembly sequence determination ‘Figure 4a’ and final model of the assembly scheme with bonds information ‘Figure 4b’. The final model of the assembly scheme with bonds information includes: 1) in the upper part, assembly diagram with graphical representation of assembly composition and assembly sequence.
of parts and subassemblies containing the numbers of operations and transitions (a two-digit numeric designation near the arrows that defines the sequence of joining parts and subassemblies); 2) in the lower part, in circles with designation of the parts positions, the assembly unit design model with designation of directions and bond rank between parts. The program results contain a matrix representation of the graph and a sequence of connecting parts.

The results obtained are the first stage in the design of assembly lines (planning of assembly section), reflect the complete structure and the order of completing the product and its components in time, allows to choose the best option from a variety of assembly options, contribute to product development for manufacturability, greatly simplify the design of the entire assembly process.

Figure 4. (a) Technique for automated assembly sequence determination, (b) The final model of the assembly scheme with bonds information
According to the certain assembly sequence, using technique for geometry deviations analyzing in assembling based on the adaptation the mathematical apparatus of the robot kinematics [24], there is an opportunity to implement a number numerical experiments in Excel:

- Determine the displacement coordinates of contact points taking into account the geometry deviations;
- Track the difference in geometry deviation between contact points;
- Assess the effect of transitions on assembly deviations.

Binding to the coordinate system and graphical visualization of the result in the Excel program of geometric models of parts and their connections allows to analyze and perform transformations with geometry deviations at the parts contact points and visually assess the effect of the propagation of deviations between parts in the assembly by changing the coordinates of the contact points and the angle of the assembly in whole and individual details. The technique for geometry deviations analyzing in assembling based on the adaptation the mathematical apparatus of the robot kinematics and the graphical result of the Excel program are presented in ‘Figure 5’.

4. Conclusions
The article discusses the integrated approach to the study of accuracy parameters using geometrical models, graphs and elements of robots kinematics as the basic elements of the unified methodology for assurance of accuracy calculating stage in precision axisymmetric products assembling. The integrated approach is to combine the developed techniques into a unified methodology for assurance of accuracy
calculating stage in precision axisymmetric products assembling. The implementation of this approach is carried out by a phased study of the construction for all accuracy parameters in a common reporting format based on key provisions. Obtained results suggest quickly make changes to the studied design based on the phased analysis according with the developed integrated approach, thus, it becomes possible to control data and decisions made during dimensional analysis of structures, designing assembly processes and analyzing geometry deviations during assembly.

5. References

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