Ensuring the collection of mechanical engineering products, taking into account the tolerances for computer-aided design in "GePARD.3D"

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Abstract. The article discusses a geometric approach to ensuring the assembly of mechanical engineering products, taking into account the spatial permissible deviations of components in computer-aided design using configuration manifolds and biquaternions. The main advantage of this approach is the modeling of assemblies taking into account the tolerances with the possibility of direct access to the tree for constructing the 3D model of the product, which greatly facilitates the user's work. The developed configuration model of the assembly and the technology for analyzing spatial dimensional relationships in the product, taking into account the tolerances and using biquaternions, allow obtaining analysis results with predictable accuracy already at the stage of geometric modeling.

1. Introduction

Analysis of the current stage of development of machine-building production shows that work to ensure the quality of products is carried out in the following main areas:

1. In the field of machine design - along the line of creating technological designs of parts, assemblies and machines, along the line of improving mathematical models and methods for conducting spatial dimensional-accuracy analysis, focused on computer-aided design.
2. In the field of technology development - along the line of the correct choice of bases and obtaining the required accuracy of processing parts, complete processing of parts in mechanical shops, creating rational technological processes for assembling machines.
3. In the field of production - in the line of strict adherence to technology, obtaining high quality manufacturing of parts, blanks of its production, as well as units from cooperative factories.
4. In the field of assembly design automation - along the line of creating CAx-systems in the concept of "digital enterprise".

The purpose of design automation is to improve the quality of products with minimal labor, material and energy resources.

Despite the tremendous advances made in recent years in the development of CAD systems, modeling methods, assembly structure representation and data analysis still require further improvement and development.
The accuracy of a product is the most important indicator of its quality, which is formed at the stage of product design and is implemented during the assembly process. The main task of the assembly is to ensure the mating of components with the required geometric accuracy parameters that will best ensure the functioning of the product. Components of high quality and recognized as suitable may either not form the required tolerances of the assembly unit, or they may not be assembled at all.

Accuracy problems arising in the process of creating complex science-intensive products are relevant not only in Russia, but throughout the world. A set of problems related to tolerances (in particular, the problem of the generalized mathematical representation of tolerances) arose in the new conditions of production with the use of computers. Research A. Reykvich [1] gave impetus to the beginning of active research in this area. The research results of a group of scientists led by A. Clement [2] contributed to the beginning of the development of a new generation of ISO standards related to tolerances [3]. Representation of geometric variations using matrix transformations is considered by D. Whitney, O. Gilbert, M. Yastrebski in [4]. Conversions represent both nominal relationships between parts and deviations due to geometric tolerances. Desrochers A, Béron V, Laperrrière L in [5] use screw parameters to simulate flat tolerance zones.

In the early stages of design, there is a problem of synthesizing a product design, expressing its function as fully as possible, taking into account many restrictions. Since at the stage of conceptual design, about 60% of the cost of the life cycle is laid, the main task is to find geometric shapes that are optimally combined with each other through assigned sets of tolerances that will best describe the design idea.

A full-fledged analysis of spatial dimensional-accuracy relationships in nodes is one of the most important tools for creating high-quality products that can function with high reliability throughout the entire service life, therefore, the CAD system's functionality must support the assigned tolerances as a natural part of the geometric 3D model of the product.

One of the important stages of technological preparation of production is design, 3D modeling and manufacture of various types of equipment. Moreover, its dimensions, geometric parameters and manufacturing accuracy are determined by the values of the geometric parameters of the corresponding components of the product. Therefore, the accuracy of the design and manufacture of tooling is not guaranteed, which leads to further overhead if the technological processes and machining programs on CNC machines of the product components and related tooling are developed on the basis of nominal 3D models. To understand the scale of losses, it is enough to say that for industries associated with a large number of complex bypass-forming equipment, the process of its creation is 60-80% of labor and funds from the total volume of the Chamber of Commerce and Industry and approximately 10-15% of the cost of the product.

Further development of the electronic model of the product involves numerous analyzes and simulations carried out at the technical design stage. Therefore, it is possible to reflect the real situation that will develop during the assembly process or during the operation of the product, to identify the accumulated errors of the real geometry of the product, if already at the stage of conceptual design the problem of creating a 3D model of the product is solved, in which tolerances and information about them are its integral part.

Today, well-known CAD systems (SolidWorks, Autodesk, 3DCS, etc.) solve the problem of architecture, laid down in the last century, by "total product development anew".

A feature of the modern stage of development of computer-aided design systems is the emphasis on the "intellectual level" of systems.

2. Geometric approach to computer-aided design and analysis of assemblies taking into account tolerances and using biquaternions in the GePARD.3D system

When specifying the surface of a part, it is necessary to take into account many different factors that affect its shape and parameters. According to the main theorem of the theory of surfaces (Bonnet's theorem), any surface is determined by uniquely specifying a pair of quadratic forms in the domain $U$ on the plane, provided that the initial conditions are specified. For a part with an elementary
topological structure, the real position of the surface can be obtained by varying the coefficients of the quadratic forms. In the case of non-elementary surfaces, it is possible to use atlases consisting of several maps, the number of which is determined by the requirement of minimality and clarity.

When designing a mechanism, the designer must assign different types of tolerances. In our approach, tolerances are represented by three main groups:

- location tolerances (they are characterized by bivectors and biquaternions that set the connection between the reference points of the initial conditions);
- bending tolerances (characterized by a change in the coefficients of the second quadratic form while keeping the first quadratic form unchanged);
- metric distortion tolerances (characterized in terms of variations of the first quadratic form).

Each part included in the product, as well as its geometric elements, for the geometric characteristics of which tolerances are assigned, are uniquely associated with configuration manifolds [6]. Each point of such a variety sets the value of those parameters that can change. Information about unchanged product parameters does not affect the design of the manifold, which makes it possible to significantly reduce the number of unknown quantities. Clear rules are set for determining all parameters of a part (product) at a given point of the configuration manifold. The variety is chosen by the designer. To obtain a new position of the geometrical element of the part with the assigned tolerance for the geometrical characteristic, we set the marked reference, the configuration manifold and its own normalized biquaternion of displacement.

The relationship between parts, with assigned tolerances and included in the product, is described by the assembly graph. To formalize these connections, we use biquaternions.

The assembly is divided into levels, each of which corresponds to a so-called C-part in the same order as the assembly level. In other words, a level k assembly is the assembly that produces a C-part of order k. So a monolithic component that cannot be divided into individual parts is called a C-part of order zero. Then a C-part of order k is a C-part obtained by assembling C-parts of order not greater than (k-1). Accordingly, the (part or assembly) level k tolerance if the result of the level k assembly depends on it, and k is the smallest such value.

If the assembly consists of the (n+1)-th level. Let us denote by \( m_j \) the number of C-parts of level \( j \) \((j = 0, 1, ..., n)\), by \( q_p \) - the number of surfaces of the \( i \)-th C-part of level \( j \) \((j = 0, 1, ..., n; i = 0, 1, ..., m)\), for which the tolerances of level \( j \) are specified, and is the number of tolerances assigned to the surface. The configuration space of the level \( j \), and \( p_{ij}^k \) of the surface \( S_{ij} \) is obtained in the form:

\[
K_j^{k} = \prod_{\alpha} K_{ji}^{k \alpha},
\]

where: \( K_{ji}^{k \alpha} \) — configuration spaces \( S_{ij} \) characterizing the deviation of the surface from the nominal values relative to one of the tolerances of level \( j \).

The configuration manifold of the assembly is obtained as follows:

\[
K = \prod_{j=0}^{n} \prod_{i=1}^{m_j} \prod_{k=1}^{q_p} \prod_{\alpha=1}^{p_{ij}^k} K_{ji}^{k \alpha}.
\]

Using biquaternions and configurational manifolds, a mathematical model of the spatial configurational dimensional chain (CDC) of the product has been developed. The developed technology of nonlinear analysis of spatial dimensional-accuracy links in assembly units to ensure collection is directly related to the technology of configurational direct modeling [7].
3. Conclusion
The research results were implemented in an experimental version of a new generation CAD system “GePARD. 3D”. Figure 1 shows an example of a spatial analysis of a node, taking into account the spatial tolerances assigned to its components, in “GePARD. 3D”.

![Spatial analysis of tolerances in GEPAKD. 3D](image)

Figure 1. Spatial analysis of tolerances in GEPAKD. 3D.

Many well-known companies are developing various approaches that are designed to provide the user with direct modeling. In this case, direct modeling is carried out in separate applications without direct access to the tree of its construction. The technology of configurational direct modeling of product geometry developed by us is free from this drawback. In addition, since the surfaces are defined by their first and second quadratic forms, it is equally convenient to work with both analytically described surfaces and free-form surfaces: import, create, edit and carry out a collection analysis taking into account the assigned tolerances.

The developed technology for ensuring the collection of mechanical engineering products, taking into account the spatial permissible deviations of components, based on new approaches to the design and manufacture of mechanical engineering products, makes it possible to ensure the required accuracy of the main geometric characteristics of the product, both by the statistical method and by the worst-case method. Its implementation is closely related to the reengineering of business processes for the provision of life cycle products at the present stage of development of mechanical engineering.

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