Implementation of an enlarged block of design procedures for the analysis of requirements for the assembly of high-precision products

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Abstract. The article considers the issue of improving methodological, mathematical and algorithmic support for the implementation of an enlarged block of design procedures of the analysis of a high-precision assembly unit and the requirements of its assembly of the system of accounting requirements for the assembly in the design of manufacturing methods of machining. The proposed improvements will make it possible to more efficiently perform design dimensional analysis of a high-precision assembly unit in an automated mode and choose rational manufacturing methods of machining of parts during process design of the production of multi-nomenclature machine building complexes.

1. Introduction
Achieving the specified operational characteristics of high-precision equipments and machines causes significant difficulties due to the influence of unknown and poorly managed reasons, which are eliminated by costly methods at the form of numerous developments, reassembles and design refinement [1,2]. One of the approaches to effectively solve these problems is the developed the complex of formalized design procedures of the system of accounting requirements for the assembly in the design of manufacturing methods of machining (SRAMMM) [3]. In general, the structure of this complex is shown in figure 1.

In this article we will consider in detail the improvement of methodological, mathematical and algorithmic support for the implementation of an enlarged block of design procedures of the analysis of a high-precision assembly unit and the requirements of its assembly of SRAMMM (in figure 1 this block is marked with the number I).

2. Formatting the title, authors and affiliations
The design dimensional analysis (DDA) consists in the construction of graphs of dimensional analysis of assembly units (graphs of conjugations) \( G_C = (B_C,C_C) \) and graphs of dimensional analysis of parts (graphs of sizes) \( G_S^j = (B_S,C_S^j) \) (j = 1...n index denotes the number of the part in the assembly).

It is advisable to start the implementation of this stage by identifying the output geometric parameters of a high-precision product or assembly units - master links (assembly requirements), the
limit of which is more stringent in comparison with the dimensional accuracy of the parts (constituent links).

Figure 1. The structure of SRAMMM.

The initial data for this step are the design documentation and the resulting databases. The procedure includes the following steps:

- Determination of all possible output geometric parameters - master links, as well as necessary for calculating the dimensions of parts - constituent links.
- Partitioning of a high-precision product or assembly unit into structural elements.
- Determination of the possible planes to which the master and constituent links belong.
- Formation of dimensional chains for the calculation of master links.
- Identification of assembly requirements that cannot be ensured by the full interchangeability method and determination of the planes in which the calculation will be performed.

Consider the first step. The accuracy requirements that the assembly joint must satisfy:

- The accuracy of the relative positions of individual parts or assembly units that ensure the proper operation of the product during its operation.
- Accuracy of the relative positioning of individual parts or assembly units ensuring the collection of the product.

At the second step a high-precision product is divided into structural elements. Structural element is an element of an assembly unit or an assembly unit as a whole with a specific functional purpose. According to the layout solution, structural elements can be conditionally divided into three groups: structural elements with a common axis of rotation, plane structural elements and combined structural elements.

For subsequent analysis subassembly must break into structural elements. This takes into account both the standard requirements for the assembly (attachments, projecting elements, etc.) and specific assembly requirements inherent in the design.

It is advisable to split a high-precision product into structural elements that differ in composition from assembly units in the event that it is necessary to calculate assembly requirements, the constituent links of which belong to different assembly units or products.
The process of splitting an assembly unit (structural element) is presented in figure 2.

![Diagram](image)

**Figure 2.** An example of a partition scheme of a structural element (assembly unit).

At the next step, planes are selected to which the corresponding output geometric parameters (assembly requirements) belong. Information about the planes to which the output geometric parameters belong can be obtained from the compiled databases of assembly units and the final product.

Next is the formation of dimensional chains for DDA. The selection of the dimensional chain by the nature of the links is based on the geometric arrangement of the components of the structural element and the nature of the master and constituent links.

To calculate the master and constituent links it is necessary to use a certain indexing of dimensions and limits. In general formulas will look like this:

\[
\begin{align*}
B_{k,l}^{i,j} &= \sum_{i=1}^{n_7} A_{k_1,m}^{i_1,j_1} - \sum_{i=n_7-1}^{n_8} A_{k_1,m}^{i_1,j_1}, \\
A_{k_1,m}^{i_1,j_1} &= \sum_{i=1}^{n_10} A_{k_1,m}^{i_1,j_1} - \sum_{i=n_10-1}^{n_11} A_{k_1,m}^{i_1,j_1}, \\
TB_{k,l}^{i,j} &= \sum_{i=1}^{n_9} TA_{k_1,m}^{i_1,j_1}, \\
TA_{k_1,m}^{i_1,j_1} &= \sum_{i=1}^{n_{12}} TA_{k_1,m}^{i_1,j_1}
\end{align*}
\]

where: \(B\) - assembly requirements (master links); index \(i\) - serial number of the requirement \((i = 1 \ldots n_7)\); index \(j\) is the number of the plane to which this requirement belongs \((j = 1 \ldots n_8)\); index \(k\) - serial number of the product \((k = 1 \ldots n_7)\); index \(l\) is the serial number of the assembly unit or structural element \((l = 0 \ldots n_8)\); \(A\) - constituent links of the design dimensional chain; index \(i_1\) is the serial number of the component link \((i_1 = 1 \ldots n_7)\), index \(k_1\) is the part number \((k_1 = 1 \ldots n_8)\), index \(m\) is the serial number of the dimension in the part \((m = 1 \ldots n_8)\); the signs \(-\) respectively indicate the increasing and decreasing constituent links of the dimensional chain; \(n_7\) and \(n_{10}\) are the number of increasing links when calculating assembly requirements and constituent links, \(n_8\) and \(n_{11}\) are the number of decreasing links when calculating assembly requirements and constituent links, \(T\) is the limit for the corresponding dimension.
Assembly requirements that fully comply with the condition:

\[
TB_{k,l}^{i,j_1} = \sum_{i=1}^{n_9} TA_{k,m}^{i,j_1}
\]  

are provided by the full interchangeability method and will not be further considered.

We are interested in the requirements that meet the following condition:

\[
TB_{k,l}^{i,j_1} < \sum_{i=1}^{n_9} TA_{k,m}^{i,j_1}
\]

that is, such requirements that cannot be met full interchangeability method.

Thus, assembly requirements are formed, which cannot be provided by full interchangeability method. Next, we consider the implementation algorithms of this enlarged block of design procedures.

To implement this enlarged block of procedures, algorithms were developed to determine the number of possible dimensional chains for a part or assembly and to calculate the nominal dimensions and limits of the possible master links of the designer dimensional chains of the part (assembly unit), taking into account the proposed indexing and mathematical models selected as prototypes \([3,4,5]\). In general, the algorithm is presented in figure 3.

![Figure 3. Algorithm of an enlarged block of design procedures.](image-url)
The initial data of the calculation are the number of surfaces of the part (assembly unit) and the graph of the design dimension chain of the part (assembly unit).

Let us consider the obtained algorithm using the example of the part “Liner” (figure 4). It can be seen from the figure that the number of part surfaces is \( n_m = 6 \). The relationships between the dimensions and surfaces of the part are illustrated by a graph (figure 4).

According to the formula A. Cayley, the number of spanning trees \( m_{S.T.} \) in a full graph at \( n \) vertices it is [6]:

\[
m_{S.T.} = n_m^{n_m - 2}.
\]

For this example, the number of possible dimensional chains will be equal to: \( m = 6^{6-2} = 1296 \).

To calculate the nominal sizes and limits of possible master links (figure 5), we formed a square vertex incidence matrix \([n_m \times n_m]\) (figure 6) and filled it out based on the relationship graph between the dimensions and surfaces of the part (dimensional relationship graph).

![Figure 4. The part “Liner”.
](image)

| Surfaces | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | ? | ? | ? |
| 2 | 1 | 0 | ? | ? | ? | ? |
| 3 | 1 | ? | 0 | 1 | ? | 1 |
| 4 | ? | ? | 1 | 0 | ? | ? |
| 5 | ? | ? | ? | ? | 0 | 1 |
| 6 | ? | ? | 1 | ? | 1 | 0 |

![Figure 6. Vertex incidence matrix of the part “Liner”](image)

The vertex incidence matrix of a graph with a finite number of vertices \( n_m \) (numbered from 1 to \( n_m \)) is a square matrix of size \([n_m \times n_m]\) in which the value of the element \( s_{ij} \) is equal to the number of edges from the \( i \)-th vertex of the graph to the \( j \)-th vertex. The vertex incidence matrix of a simple graph (not containing loops and multiple edges) is a binary matrix and contains zeros on the main diagonal. Matrix elements are defined as follows: equal to one if an arc enters from vertex \( n_i \) to vertex \( n_j \); is equal to zero if the arc does not enter from the vertex \( n_i \) to the vertex \( n_j \).
3. Conclusion

Thus, the improvement of methodological, mathematical and algorithmic support for the implementation of an enlarged block of design procedures of the analysis of a high-precision assembly unit and the requirements of its assembly will allow more efficient design dimensional analysis of the high-precision assembly unit in an automated mode and in the future choose rational manufacturing methods of machining of parts in the system of automated sequencing of manufacturing methods [6] during process design of multiproduct machine-building complexes. In addition, the modernization of this stage allows to establish a connection between the designing preproduction and process design.

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