Investigation of the influence of the set-making strategies on the indicators of the two-parameter selective assembly of two elements

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Abstract. The technological process of two-parameter selective assembly of two elements is considered. Two various strategies for selective set-making of two multi-parameter elements are given. The first one is simultaneous set-making, when using it, the elements are simultaneously sorted into multidimensional groups according to all parameters, and then they are set-made and assembled. The second strategy consists in the selection of elements sequentially for each of the parameters. The main indicators of the assembly process are determined. The models of the assembly of elements are made allowing for the selected strategy to determine the total probability of obtaining suitable assembled sets, the probability of incomplete elements, forming work in progress and preliminary scrappage. The investigation of the influence of the different set-making strategies on the indicators of the assembly process is made. An example is given that clearly shows the results of determining key indicators of the process using various procedures. Advantages and disadvantages of each strategy are identified.

1. Introduction
The conjugation of elements in several parameters is often found in mechanical engineering and instrumentation. The first works in the field of combining of selective assembly and fitting for a multi-link dimension chain with conjugation in several parameters are described in [1]. The fundamental theoretical work on the issues of selective assembly is the monograph [2], in which the authors propose a new methodology for solving problems associated with this process, based on a systematic approach and an algorithmic method of analysis and synthesis. It considers both traditional and more complex tasks associated with the multi-parameter assembly of two or more elements. Further development of studies related to single- and multi-parameter selective set-making and taking into account the influence of various random factors on this process is described in works [3–11].

There are various strategies for selective set-making of two multi-parameter elements. The main one is the strategy of simultaneous set-making. When using it, the elements are simultaneously sorted into multidimensional groups according to all parameters, and then they are set-made and assembled. There is another strategy, which consists in the selection of elements sequentially for each of the parameters. The first strategy is called simultaneous, and the second one is sequential. Their application is described in [2].

This paper presents an investigation of the influence of the different set-making strategies on the indicators of the process of two-parameter selective assembly of two elements.
2. Materials and methods

Let us consider the assembly of two elements, each of which is characterized by parameters $x_{is}$ ($i = 1, 2$, $s = 1, 2$). The scheme of such process is shown in Figure 1.

![Figure 1. The scheme of two-parameter set-making of two elements](image)

We assume that elements are independent from each other, the parameters are uncorrelated; the corresponding one-dimensional distributions of parameters are considered known and are indicated $f_{is}(x_{is})$; the output parameters of the assembled product associated with the input linear dependencies:

$$y_i = \sum_{j=1}^{2} b_{is} x_{is}, \quad (i = 1, 2, \; s = 1, 2), \; b_{is} = \text{const}.$$  

A generalized model of the process of two-parameter selective assembly of two elements was constructed in [12]. The tolerance intervals of the selective groups for each of the element parameters will be indicated $X_{(k_{is})}$, where $k_{is}$ is the group number of the parameter $s$ of the element of type $i$. The limiting deviations $a_{is}$ of the selective groups break down the entire range of parameter values at $l_{is}$ intervals $X_{(k_{is})}$, each of which has boundaries $(a_{is}^{(k_{is})}; a_{is}^{(k_{is}+1)})$. Let’s accept that elements of one group may enter into the set of only one type.

1. Strategy of simultaneous set-making.

The multidimensional group includes elements whose parameters simultaneously satisfy the requirements $x_1 \in X_{(k_{i1})}$, $x_2 \in X_{(k_{i2})}$, the proportion of such elements from the total amount is determined by the formula:

$$I_i^{(k_{is})} = \prod_{j=1}^{2} I_j^{(k_{is})}, \; (i = 1, 2),$$

where $I_i^{(k_{is})}$ is the number of elements of type $i$ whose parameter $s$ belongs to the $k_{is}$ one-dimensional group $X_{(k_{is})}$:

$$I_i^{(k_{is})} = \int_{a_{is}^{(k_{is})}}^{a_{is}^{(k_{is}+1)}} f_{is}(x_{is}) dx_{is}.$$  \hspace{1cm} (1)

Then in the groups with the numbers 1 and 2 outside the boundaries of the tolerances the elements are got with the probabilities:

$$I_i^{(l_{is})} = \int_{-\infty}^{a_{is}^{(k_{is})}} f_{is}(x_{is}) dx_{is}, \; I_i^{(u_{is})} = \int_{a_{is}^{(k_{is}+1)}}^{\infty} f_{is}(x_{is}) dx_{is}.$$ 

The sum of these probabilities is the probability of preliminary scrappage; elements from these groups are excluded from the completion process. Then the probability of obtaining the assembly of the $k$ type can be determined by the formula:
\[ I_{ck}^{(k)} = \min \{I_{1}^{(k)}; I_{2}^{(k)}\}, \quad k = 1, L. \]

The total probability of obtaining suitable assembly sets for all selective groups is:
\[ I_{ck} = \sum_{k} I_{ck}^{(k)}. \]  \hfill (2)

The probability of incomplete elements forming incomplete production and preliminary scrappage is equal to:
\[ P = 1 - I_{ck}. \]

2. Strategy of sequential set-making.

The number of elements of type \( i \) whose parameter \( s \) belongs to the \( k_{i} \), one-dimensional group \( X_{i}^{(k_{i})} \) is defined by the expression (1). First, the elements are selected according to any one parameter, and then among the sets pre-selected in this way, the elements corresponding to each other according to the second parameter are selected. In this case the probability of obtaining the assembly of the \( k \) type is determined by the formula:
\[ I_{ck}^{(k)} = \min \{I_{1}^{(k_{i})}; I_{2}^{(k_{i})}\} \times \min \{I_{1}^{(k_{i})}; I_{2}^{(k_{i})}\} = \prod_{s=1}^{2} \min \{I_{1}^{(k_{i})}; I_{2}^{(k_{i})}\}. \]

The total probability of obtaining suitable assembly sets for all selective groups and the probability of incomplete elements forming incomplete production and preliminary scrappage are equal to:
\[ I_{ck} = \sum_{k} I_{ck}^{(k)}, \quad P = 1 - I_{ck}. \]  \hfill (3)

3. Simulation results

Here is an example of modeling using different strategies for elements set-making. We suppose that batches of elements (parts) of identical volumes are produced. The arrangement of tolerance intervals for each parameter with the boundaries of the selective groups are shown in Figure 2.

Let us assume that:
1) the distributions of parameters elements are Gaussian with densities:
\[ f_{is}(x_{is}) = \frac{1}{\sigma_{is} \sqrt{2\pi}} e^{-\frac{(x_{is} - m_{is})^2}{2\sigma_{is}^2}}, \quad (i = 1, 2; \quad s = 1, 2), \]

where \( m_{is} \) and \( \sigma_{is} \) are the mean (mathematical expectations) and standard deviation of a random
variable $x_i$;

2) the parameters of distributions of random variables:
   - means $m_{11} = 4.0$ μm; $m_{12} = 9.5$ μm; $m_{21} = 2.0$ μm; $m_{22} = 6.5$ μm;
   - standard deviations $\sigma_{11} = 1.731$ μm; $\sigma_{12} = 3.846$ μm; $\sigma_{21} = 1.552$ μm; $\sigma_{22} = 3.448$ μm;

3) the output parameters of the product are the clearances, which must belong to the specified ranges: $S_1 = x_{11} - x_{21} \in [0; 6]$ μm; $S_2 = x_{12} - x_{22} \in [0; 8]$ μm.

The one-dimensional distributions $f_i(x_i)$ when combining the coordinates of the midpoints of tolerance intervals are shown in Figure 3, the densities of two-dimensional distributions are shown in Figure 4.

![Figure 3](image1.png)

**Figure 3.** The one-dimensional distribution densities ($- f_1(x_{11})$; $- - - f_2(x_{22})$)

![Figure 4](image2.png)

**Figure 4.** The two-dimensional distribution densities

The total probabilities of obtaining suitable assembly sets determined by formulas (2) and (3) for this example are equal:
- for the simultaneous strategy $I_{CK} = 0.752$;
- for the sequential strategy $I'_{CK} = 0.718$.

4. Conclusion
For this example, the indicators of the assembly process, depending on the choice of set-making strategy, differ by 4.5%. Sequential set-making is always easier to organize in practice. However, sequential and simultaneous procedures are not equivalent: simultaneous set-making always gives the best result. In some cases, the difference can reach 20%.

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