Modeling of dimension chains of pressure control devices

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Abstract. The article is devoted to pressing issues in the field of instrumentation and measuring equipment: the correct assignment of tolerances and landings in the manufacture and assembly of parts and assemblies of measuring transducers of physical quantities. In the process of developing converters, an obligatory design procedure is the construction of mathematical models of dimensional chains, which are analytical and numerical equations consisting of geometric dimensions shown in the drawings. Moreover, these models include both nominal geometric and angular dimensions, and the tolerances adopted on them. Using the minimum-maximum methods, it is quite simple to calculate the dimensional chains for simple parts and assemblies. Complex parts and assemblies having a large number of sizes included in the dimensional chains are calculated by statistical methods using specialized programs.

1. Introduction

The article is devoted to model development of dimension chains of pressure control devices. Dimension chains allow correctly reassemble the pressure control devices with minimal modifications and trimming means. The basic concepts and equations of the dimension chains theory are described. The tasks automating calculations of dimension chains are determined and ways of their solutions are scheduled. To normal functioning of units and the whole sensor in general it is necessary that their constituent parts and surfaces occupy relatively to each other a certain position that dictates the need to address interrelated dimensions, their allowances, deviations, interaction to each other [1, 2]. To describe this process, we use the calculating theory of dimension chains (DC) which is widely used in the mechanical - and instrument engineering industry [3, 4]. When developing the DC applied to two-level ventilation (TLV), we introduce the following classification concepts:

Dimension chain – is a size combination generating close circuit.

Dimension chain scheme - is a graphical representation of DC, which is drawn separately from the unit drawing. In this case, there are different zooming in, zooming out and trailing sizes. Dimensions in DC are called links and are marked by capital letters of the Russian alphabet or lowercase letters of the Greek alphabet. The link of DC is the source link in the problem statement or the latest link as a result of its decision is called master link and is denoted with index Δ, for example HΔ, aΔ and etc. The links of DC may serve as compensating links, which serve to maintain the links circuit required accuracy (figure 1).
Let us represent in the general form the procedure for DC calculating, using the recommendations set out in the regulations and special technical literature [5, 6].

First, it must be noted that the most important prerequisite for the compilation and analysis of graphical models of DC is the condition of its circularity.

In the calculations, we use the following notation:

$A_j (j = 1, 2, \ldots, m-1)$ – nominal size of the undefined link of dimension chain; $A_0$ – nominal size of the master link of dimension chain; $TA_j, TA_0$ – tolerances described above sizes; $A_j^{\text{max}}, A_j^{\text{min}}, A^c_j$ – respectively marginal and average size of the chain links; $ES(A_j), EJ(A_j), Ec(A_j)$ – marginal and average deviation of the size of dimension chain (figure 2).

![Figure 1. Classification model of dimension chain links.](image1)

![Figure 2. Graphic model of tolerances and dimensions location DC links numbers: $m$ – total number of links; $n$ – number of zooming up links; $p$ – number of zooming out links.](image2)

2. Theoretical ground

The solution is made by the formulas:

$$A_0 = \sum_{j=1}^{n} \hat{A}_j - \sum_{n+1}^{m} \bar{A}_j$$  \hspace{1cm} (1)

$$ESA_0 = \sum_{j=1}^{n} ESj \hat{A}_j - \sum_{n+1}^{p} EJ \bar{A}_j$$  \hspace{1cm} (2)

$$EJA_0 = \sum_{j=1}^{n} EJA_j - \sum_{n+1}^{p} ESA_j$$  \hspace{1cm} (3)

$$TA_0 = \sum_{j=1}^{m-1} TA_j; \quad TA_j = TA_0 - \sum_{j=1}^{m-2} TA_j$$  \hspace{1cm} (4)

$$EcA_0 = \sum_{j=1}^{n} Ecj \hat{A}_j - \sum_{n+1}^{p} Ec \bar{A}_j$$  \hspace{1cm} (5)
\[
\text{ESA}_0 = \text{EcA}_0 + \frac{\text{TA}_0}{2} \tag{6}
\]
\[
\text{EJA}_0 = \text{EcA}_0 - \frac{\text{TA}_0}{2} \tag{7}
\]

As part of the settlement method, max-min calculation may be performed in two ways:

2.1. The method of equal tolerances \([7]\)

This method is applied when the DC components are close in size, or belong to the same size range in the table of tolerances.

\[
\text{TA}_1 = \text{TA}_2 = \ldots = \text{TA}_{m-1} = T_{\text{cp}} \cdot A_j \tag{8}
\]

\[
\text{TA}_0 = (m - 1) \cdot T_{\text{cp}} \cdot A_j \tag{9}
\]

\[
T_{\text{cp}} \cdot A_j = \frac{T \text{A}_0}{m - 1} \tag{10}
\]

2.2. The method of quality class tolerances (equally accurate tolerances)

All component links make one quality class accuracy. The required quality class is defined as follows.

The tolerance of the component size:

\[
\text{TA}_j = a_j \cdot i \tag{11}
\]

\[
i = 0,45 \cdot \frac{1}{\sqrt[3]{D}} + 0,001 \cdot D \tag{12}
\]

where as \(D\) – geometric average size for the interval by condition: \(a_1 = a_2 = \ldots = a_{m-1} = a_{\text{cp}}\).

\[
\text{TA}_0 = a_{\text{cp}} \sum_{j=1}^{m-1} (0,45 \cdot \frac{1}{\sqrt[3]{D}} + 0,001 \cdot D) \tag{13}
\]

\[
a_{\text{cp}} = \frac{T \text{A}_0}{\sum_{j=1}^{m-1} (0,45 \cdot \frac{1}{\sqrt[3]{D}} + 0,001 \cdot D)} \tag{14}
\]

where as \(T\) expressed in microns, and \(D\) - in mm.

3. The algorithm for calculating the DC \([8]\)

By \(a_{\text{calc}}\) it is determined the quality class (Table \((a_{\text{calc}} \sim a_{\text{table}})\).

By this quality class there are assigned the tolerances for constituent sizes of DC.

\(\text{TA}_1 = \ldots, \quad \text{TA}_2 = \ldots, \quad \text{TA}_3 = \ldots\)

It is necessary to compensate the tolerances for constituent sizes of DC so that the sum \(\text{TA}_j\) should be equal to \(\text{TA}_0\) (since \(a_{\text{calc}} \neq a_{\text{table}}\), then \(\sum \text{TA}_j \neq \text{TA}_0\)).

It is necessary to assign tolerances extremes to constituent sizes (to covering dimensions at "H" (+), to covered dimensions at "h" (-), in difficult to detect cases the tolerance is assigned symmetrically (\(\pm\))).

Tolerance extreme of the same size is determined by the formulas:

\[
\text{ESA}_0 = \sum \text{ES}A_j - \sum \text{EJA}_j \tag{15}
\]

\[
\text{EJA}_0 = \sum \text{EJA}_j - \sum \text{ESA}_j \tag{16}
\]

thus it is necessary to satisfy the condition: \(\text{TA}_0 \geq \sum_{j=1}^{m-1} \text{TA}_j\)
4. The methods for automating calculations of DC

It should be noted that currently the calculation algorithms of DC are advisory in nature. It is used in the calculation a significant number of features: the risk ratio, the ratio of the relative scattering effect, the economic machining precision, the standard tolerances and others. This complicates the implementation of calculations with the required accuracy.

As shown earlier, any DC is a collection of constituent links as determined by the actual value of the trailing link of DC. Dimensions of constituent links are random variables. Consequently, the master link of DC is also a random variable. This makes it possible to use in the calculation of DC the statistical modeling methods. One of similar method is the method of statistical tests (Monte Carlo method) [5]. It is currently used in the relevant modules of modern CAD / CAM / CAE systems, such as Proingeneer, Solid Works, Catia and etc [9, 10].

The essence of the Monte Carlo method for dimensional calculations is repeated modelling of aggregate certain links under the terms of the calculation with certain laws of distribution, to obtain an array of values of the desired link and follow the statistical processing of the array to obtain the features of the desired link of DC. The integrated circuit of the Monte Carlo method for solving the inverse problem of DC calculating is shown in Figure. For each test \( k = 1 \ldots N \) it is produced one collection of constituent links and the value of master link \( A_{\Delta k} \) is found,

\[
A_{\Delta_k} = \sum_{i=1}^{m-1} A_{ix} \xi_i, \tag{17}
\]

where as \( A_{ix} \) – the nominal value of \( i \)-th constituent links at \( k \)-th test; \( \xi_i \) – gear ratio of the \( i \)-th constituent links.

From the obtained one-dimensional array \( A_{\Delta_k} \) links of length \( N \) is carried out determination of master link sizing features (figure 3).

The main advantage of Monte Carlo method is the most natural process representation of the error formation of master link of DC. This eliminates to cancel the separation methods for calculating of DC to calculations by the "maximum-minimum" and probabilistic method. In addition, eliminating the need for empirical coefficients with respect to scattering effect \( i \), characterizing the tolerance of the statistical laws of constituent links from normal. Thus, the Monte Carlo method is the most versatile, allowing to simplify the method of calculating of DC. To implement this method it is necessary the mandatory use of computer equipment. Application of the Monte Carlo method allows for a focused search of variants of decisions and mutual influence of constituent links. The accuracy of the results achieved significantly depends on the modeling of random variables and the number of tests \( N \). As the number of test is increasing, the accuracy and repeatability are increasing, but at the same time, the complexity of the calculations is increased, and the demands are increased to the hardware used.
Figure 4 and 5, table 1 and 2 show examples of RC modeling specific pressure sensors [3, 4].

![Diagram](image1)

**Figure 4.** Assembly drawing of metal sensor and dimensional model of pressure sensor circuit.

| Name          | Symbol | Nominal size, mm | Upper deviation, mm | Lower deviation, mm |
|---------------|--------|------------------|---------------------|---------------------|
| Bushing       | A      | 2,3              | 0,05                | 0,05                |
| Element       | B      | -1,2             | 0,05                | 0,05                |
| perceiving    | B1     | 6,2              | -                   | 0,09                |
| B2            | -3     | 0,04             | -                   | -                   |
| Housing       | C      | 41               | -                   | 0,25                |
| Cable         | D      | 470              | 30                  | 30                  |
| Bushing       | E      | 33               | -                   | 0,25                |
| Electrical    | F      | 1,4              | -                   | -                   |
| connector     | F1     | 7                | 0,2                 | -                   |
| X             |        | 556,7            | 30,34               | 30,69               |

**Table 1.** Assembly variables for quick variable pressure sensor of 5 to 80 kg/cm²

\[ X = 556,7^{30,34}_{-30,69} \]

\[ X_{\text{nom}} = 556,7; \quad X_{\text{max}} = 587,04; \quad X_{\text{min}} = 526,01 \]

![Diagram](image2)

**Figure 5.** Assembly drawing of the node of the receiving element (a) and its dimensional chain (b).
Table 2. Parameters of the assembly circuit of the receptor element assembly of 5 to 80 kg/cm².

| Name              | Symbol | Nominal size, mm | Upper deviation, mm | Lower deviation, mm |
|-------------------|--------|------------------|---------------------|---------------------|
| Receptive element | A₁     | 13.7             | -                   | 0.11                |
|                   | A      | -1.2             | 0.05                | 0.05                |
| Bush              | B      | 2.3              | 0.05                | 0.05                |
|                   | B₁     | -13.7            | 0.18                | -                   |
|                   | X      | 1.1              | 0.28                | 0.21                |

\[ X = 1.1^{+0.28}_{-0.21}, \ X_{\text{nom}}=1.1; \ X_{\text{max}}=1.38, \ X_{\text{min}}=0.89 \]

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