OPTIMIZING THE CONSTRUCTION OF DEVICES TO CONTROL INACCESSIBLE SURFACES - CASE STUDY

E L Niţu\textsuperscript{1}, A Costea\textsuperscript{1}, M D Iordache\textsuperscript{1}, A D Rizea\textsuperscript{1} and Al Babă\textsuperscript{1}

\textsuperscript{1}University of Piteşti, Manufacturing and Industrial Management Department, Târgul din Vale Street No.1, Piteşti, Romania

Abstract. The modern concept for the evolution of manufacturing systems requires multi-criteria optimization of technological processes and equipments, prioritizing associated criteria according to their importance. Technological preparation of the manufacturing can be developed, depending on the volume of production, to the limit of favourable economical effects related to the recovery of the costs for the design and execution of the technological equipment. Devices, as subsystems of the technological system, in the general context of modernization and diversification of machines, tools, semi-finished products and drives, are made in a multitude of constructive variants, which in many cases do not allow their identification, study and improvement. This paper presents a case study in which the multi-criteria analysis of some structures, based on a general optimization method, of novelty character, is used in order to determine the optimal construction variant of a control device. The rational construction of the control device confirms that the optimization method and the proposed calculation methods are correct and determine a different system configuration, new features and functions, and a specific method of working to control inaccessible surfaces.

1. Introduction
The complex optimization of all activities at the design, manufacturing and operation stages [1-3] require an objective analysis of the technological processes in which the orientation and fixing device of the semi-finished products is an important component of the system which also includes the machine tool, the tool and the human factor.

The present work is a continuation of the previous one, which proposes an organological study of constructive variants for structures to establish the optimal solution for construction configuration, operation and working method of a new type of device designed to control the inaccessible surfaces of the parts to be measured.

2. Optimization methodology for the construction of control devices
The diversity of constructive variants for making devices, machines and manufacturing systems [1, 4] generates difficulties in establishing rational solutions to technological equipment, which can only be overcome by means of optimization methods.

2.1. Algorithm to design-optimize the construction of control devices
For a more rigorous analysis of the precision of machining or control required by the technical documentation and the establishment of well-grounded technical solutions, the previous paper

\* eduard.nitu@upit.ro
proposed a design-optimization algorithm for the construction of devices, in general, a particular case in Figure 1 for the construction of devices to control inaccessible surfaces. The signification of optimizing stages \(E_{01}, E_{02}, \ldots, E_{08}\) is the same as in the previous paper.

2.2. Optimizing the construction of devices to control inaccessible surfaces - case study

In many situations, especially in the case of subassemblies, certain surfaces cannot be controlled because they are in contact with the supports of the device, which make it impossible for the measuring elements to reach the work areas, and other surfaces have components assembled on them.

For this reason, there was defined the design-optimization algorithm presented in Figure 1, the working stages of this algorithm will be practiced on a case study of the water pump subassembly of the automotive engines for the construction of control devices.

E01 – Knowing or determining SOF-O

Initially, the quotas and conditions imposed on the analyzed control operation and the optimal orientation and fixing scheme (SOF-O) are known as a combination of graphical signs of the information symbolization of the orientation and fixing bases of the semi-finished products shown in Figure 2.

SOF-O = (1) + (4) + (5) + (9) + (12) + (10)

The numbers of symbols in SOF-O have been preserved as in [5].

E02 Coding the construction variants of the orientation and fixing elements of the device

Constructive variants of structures, which are known, are defined and coded for each symbol element of quotation bases BCI, BCII, BCIII and fixing bases BFIV, BFV in the optimal orientation and fixing scheme set forth in [5], or new constructive variants to be achieved later can also be analyzed.

System of main orientation supports:
BCI - (1) \(\bullet\bullet\) \(X_{11}\) - short fixed prism mono-block;
X_{12} - short adjustable prism mono-block;
X_{13} - short fixed prism from two semi-prisms;

BCII - (4)  
- X_{21} - planar flat base plate type mono-block;
- X_{22} - planar flat base defined by three adjustable dowels with spherical contact heads;
- X_{23} - planar flat base made of three adjustable dowels with planar oscillating contact surfaces, in modular version;

BCIII - (5)  
- X_{31} - fixed planar support base (fixed dowel);
- X_{32} - adjustable planar support base (adjustable dowel);

Fixing system with additional supports:
BFIV - (9)  
- X_{41} - additional support with self-positioning and subsequent blocking, as adjusting force;

BFV - (12)  
- X_{51} - additional support with self-positioning and subsequent blocking, as adjusting force and as main force, finally.

These additional supports (9, 12) will be analyzed in a single construction variant to simplify the presentation of this work, but these or other fixing components, bodies, guidance systems, or base plates may be analyzed by this method.

E03 – Establishing the optimizing technical criterion
The optimizing technical criterion is that of precision that becomes eliminatory and requires the technically acceptable constructive solution (SC-TA) to meet condition $\varepsilon_{c,T}^{o-p} < \varepsilon_{ad,T}^{o-p}$, where:
- $\varepsilon_{c,T}^{o-p}$ - orientation-position error of the structure construction;
- $\varepsilon_{ad,T}^{o-p}$ - orientation-position error admitted for the structure.

These two types of errors are calculated with relations presented in [4, 6] and are introduced in Table 1 centralizing the optimizing variants and criteria.

For BCI-SI (short fixed prism)
Calculation $\varepsilon_{ad,T}^{o-p}$

$$\varepsilon_i = \sqrt{\varepsilon_0^2 + \varepsilon_f^2 + \varepsilon_d^2}$$  \hspace{1cm} (1)

where, $\varepsilon_i$, $\varepsilon_f$, $\varepsilon_d$ are defined in [4] and the previous paper.

The admissible installation error ($\varepsilon_{ad}$) is calculated for the control device with relation:

$$\varepsilon_{ad} = (\frac{1}{5} \cdots \frac{1}{10}) T_p$$  \hspace{1cm} (2)

where, $T_p = 0.080$, is the tolerance of the part at the quotation / condition analyzed.

The precision condition is $\varepsilon_i \leq \varepsilon_{ad}$.

$\varepsilon_o = 0$, because BC $\equiv$ BO, and the orientation prism of the control device is identical to that of the processing operation.

$\varepsilon_f = \max. 0.010$, due to the self-positioning and subsequent blocking fixing system.

From relation (1) it can be written:

$$\varepsilon_d = \sqrt{\varepsilon_i^2 - (\varepsilon_0^2 + \varepsilon_f^2)}$$ and: $\varepsilon_{d,\text{max}} = \sqrt{(\frac{1}{5} \cdot 0.080)^2 - (0^2 + 0.010^2)} = 0.012$

$\varepsilon_{ad,T}^{o-p} = \varepsilon_{d,\text{max}} = 0.012$

Calculation $\varepsilon_{c,T}^{o-p}$

$X_{11}$ - short fixed prism mono-block (Figure 3): $\varepsilon_{c,T}^{o-p} = 0.010$, as execution and assembly precision;

$X_{12}$ - short adjustable prism mono-block (Figure 4): $\varepsilon_{c,T}^{o-p} = 0$, as execution precision and possibility to adjust and block;

$X_{13}$ - short fixed prism from two semi-prisms (Figure 5): $\varepsilon_{c,T}^{o-p} = 0.020$, as execution and assembly precision.
Figure 3. Short fixed prism mono-block

Figure 4. Short adjustable prism mono-block

Figure 5. Short fixed prism from two semi-prisms

For BCII-SI_{oII} (planar flat base)

Calculation $\varepsilon^0_{ad,s}$

There are used the relationships (1) and (2). From the part drawing [5]: $T_p = 0.100; \varepsilon_o = 0$ because $BC \equiv BO; \varepsilon_f = \text{max. 0.010 due to the self-positioning and subsequent blocking fixing system.}$

$$\varepsilon_{d_{\text{max}}} = \sqrt{\left(\frac{1}{5} \cdot 0.100\right)^2 - (0^2 + 0.010^2)} = 0.017 \quad \Rightarrow \quad \varepsilon^0_{ad,s} = \varepsilon_{d_{\text{max}}} = 0.017$$

Calculation for $\varepsilon^0_{c,s}$:

$X_{21}$ -- planar flat base mono-block:

$\varepsilon^0_{c,s} = 0.015 \ldots 0.020$, as deviation from of a planar surface

$X_{22}$ -- planar flat base defined by three adjustable dowels with spherical contact heads:

$\varepsilon^0_{c,s} = 0.010 \ldots 0.020$, due to the prints on the surface of the low-hardness part

$X_{23}$ -- planar flat base defined by three adjustable dowels with planar oscillating head:

$\varepsilon^0_{c,s} = 0$, planar contact surfaces of dowels do not produce any more local deformations

For BCIII-SI_{oIII} (planar fixed restrained base)

Calculation $\varepsilon^0_{ad,s}$

There are used the relationships (1) and (2). From the part drawing [5]: $T_p = 0.080; \varepsilon_o = 0$ because on the control device the part is oriented on the same surface and support as for the processing operation; $\varepsilon_f = \text{max. 0.010 due to the self-positioning and subsequent blocking fixing system.}$

It results: $\varepsilon^0_{ad,s} = 0.012$

Calculation for $\varepsilon^0_{c,s}$:

$X_{31}$ -- narrow planar fixed base

$\varepsilon^0_{c,s} = 0.010$, as execution and assembly precision

$X_{32}$ -- narrow planar adjustable base.

$\varepsilon^0_{c,s} = 0$, because the execution errors ($\approx 0.010$) can be cancelled by adjustment.

For BFIV-SI_{IV} (pre-fixing system with self-positioning and subsequent blocking)

$X_{41}$ -- (a single constructive variant is analyzed to simplify calculations)

$\varepsilon^0_{ad,s} = 0.012$, like for the other types of structures.

$\varepsilon^0_{c,s} = 0$, due to the self-positioning and subsequent blocking fixing system.

For BFV-SI_{V} (pre-self-positioning and subsequent blocking fixing system)

$X_{51}$ -- (a single constructive variant is analyzed to simplify calculations)

$\varepsilon^0_{ad,s} = 0.012$, like for the other types of structures.

$\varepsilon^0_{c,s} = 0$, due to the self-positioning and subsequent blocking fixing system.

E04 – Establishing the economical optimization criteria

The six economical optimization criteria are established with the significance presented in the previous paper.

To simplify calculations, only two optimization criteria are chosen, cost ($C_c$) and flexibility ($C_l$).
Cost criterion ($C_c - CE_3$)

Calculate the actual cost of materials, workmanship and heat treatment costs or operating costs for each $X_{ij}$-coded structure and introduce data in Table 1. These values, in lei, are: $X_{11}=346.5; X_{12}=807; X_{13}=247.5; X_{21}=623; X_{22}=311.5; X_{23}=51.9; X_{31}=51.75; X_{32}=12.3; X_{33}^{*}=200.62; X_{51}^{*}=200.62$. Variants with sign * are modular structures.

Flexibility cost ($C_f - CE_6$)

Calculate the degree of flexibility to adjust in time ($G_{AT}$) with relation $G_{AT} = e^{-(TR/TRO)}$, where the terms have the significance of the previous paper and [7] and the values of time TR and TRO, in minutes, are:

- BCI-SI0i, $X_{11}$ - (TR = 1920'; TRO = 1920'), $G_{AT}^{X_{11}} = e^{-\left(\frac{1920}{1920}\right)} = \frac{1}{e} = 0.3678$

By proceeding similarly for the other structures as well it is obtained: $G_{AT}^{X_{12}} = 0.1353, G_{AT}^{X_{13}} = 0.2865$

- BCI-SI0ii $G_{AT}^{X_{21}} = 0.3678, G_{AT}^{X_{22}} = 0.4114, G_{AT}^{X_{23}} = 0.9931$

- BCI-SI0III $G_{AT}^{X_{11}} = 0.3678, G_{AT}^{X_{12}} = 0.979$

- BFIV-SI0iv $G_{AT}^{X_{11}} = 0.999$

- BFV-SI0v $G_{AT}^{X_{11}} = 0.999$

E05 – Defining the optimization method

Determining the optimal solution of the structure variants for the construction of the device implies the customization of the global utility method in the analyzed case.

*The calculation of the coefficients of importance for the precision criterion ($CI_{pr}$)* is done by the inverse interpolation method, with relation $CI_{pr} = 1 - CI_c$, from the previous work, and their values are presented in E06 and introduced in Table 1.

*The calculation of the coefficients of importance for the cost criterion ($CI_c$) and of the coefficients of importance for the flexibility criterion ($CI_f$) is based on the interpolation method for the minimization feature from [8] with relation:

$$CI_{c}^{X_{ij}} = \frac{\max(X_{ij}^{c}) - X_{ij}^{c}}{\max(X_{ij}^{c}) - \min(X_{ij}^{c})} \quad (3)$$

$$CI_{f}^{X_{ij}} = \frac{\max(X_{ij}^{f}) - \min(X_{ij}^{f})}{\max(X_{ij}^{f}) - \min(X_{ij}^{f})} \quad (4)$$

where, $i = 1, ..., m; j = 1, ..., n$

- $CI_{c}^{X_{ij}}$ – coefficient of importance of cost for structure variant $X_{ij}$;
- $\max(X_{ij}^{c})$ - maximum cost for structure variant $X_{ij}$;
- $\min(X_{ij}^{c})$ - minimum cost for structure variant $X_{ij}$;
- $X_{ij}^{c}$ - actual cost for structure variant $X_{ij}$;
- $CI_{f}^{X_{ij}}$ – coefficient of importance of flexibility for structure variant $X_{ij}$;
- $\max(X_{ij}^{f})$ - maximum flexibility for structure variant $X_{ij}$;
- $\min(X_{ij}^{f})$ - minimum flexibility for structure variant $X_{ij}$;
- $X_{ij}^{f}$ - actual flexibility for structure variant $X_{ij}$.

Values $CI_{c}^{X_{ij}}$ and $CI_{f}^{X_{ij}}$ will be calculated in E06 and introduced in Table 1.

E06 – Formulating the centralizing table of constructive variants and optimization criteria

Table 1 with the $X_{ij}$ variants of the five groups of structures BCI, ..., BFV, the three optimization criteria ($CI_{pr}, C_c - CE_3, C_f-CE_6$), is built and completed with the actual and admissible values calculated in E03 and E04, but also with the values of the coefficients of importance, as follows.
Coefficients of importance for the precision criterion (C_{pr}) - Inverse Interpolation Calculation Method

The notes, actual and admissible values are those in E_{03}.

For X_{11}:
- Value of interval: v_i = e^{a_o}_{ad. s} - e^{a_o}_{c_s} = 0.012 - 0.010 = 0.002
- Number of intervals: n_i = \frac{e^{a_o}_{ad. s} - \min e^{a_o}_{c_s}}{v_i} = \frac{0.012 - 0}{0.002} = 6
- Coefficient of importance of the interval: CI_i = \frac{1}{n_i} = \frac{1}{6} = 0.16
- Number of affective intervals: n_{ie} = \frac{e^{a_o}_{c_s}}{v_i} = \frac{0.010}{0.002} = 5
- Apparent importance coefficient: CI_a = n_{ie} \cdot CI_i = 5 \cdot 0.16 = 0.8
- Coefficient of importance of precision: CI_{pr} = 1 - CI_a = 1 - 0.8 = 0.2

Proceeding similarly for the other structure variants, it is obtained:
C_{pr}^{X_{12}} = 1; C_{pr}^{X_{13}} = 0.020; C_{pr}^{X_{21}} = 0; C_{pr}^{X_{22}} = 0; C_{pr}^{X_{23}} = 1; C_{pr}^{X_{24}} = 0.2; C_{pr}^{X_{25}} = 1; C_{pr}^{X_{26}} = 1; C_{pr}^{X_{27}} = 1

Table 1. Centralizing table of constructive variants and optimization criteria

| Nb. | Structure variants for BCI, ..., BFV | Precision criterion (C_{pr}) | Economical criteria – CE and Importance coefficients - CI | \Sigma CI | Decision |
|-----|-------------------------------------|-----------------------------|---------------------------------------------------------|----------|----------|
|     | Actual values [mm]                 | Cl_{pr}                     | Cost criterion \(C_c - CE_3\)                          | Flexibility criterion \(C_f - CE_6\) | (Max) | Optimal |
| BCI | \(e^{a_o}_{c_s} = e^{a_o}_{ad. s}\) | Cl_{pr}                     | Actual val. [mm]                                      | Cl_{f}   | Actual val. [mm] | Cl_{f}   | \(k_{f}\) (Max) |
| 1   | \(0.010\)                          | 0.012                       | 0.2                                                    | 1        | 346.5          | 0.57    | 1.2          | 0.3678     | 0.26      | 1.3          | 1.222 | Opt. BCI |
| 2   | \(0\)                             | \(0.012\)                   | 1                                                      | 1        | 807            | 0       | 1.2          | 0.1353     | 0         | 1            | 1     | -- |
| 3   | \(0.020\)                         | \(0.012\)                   | 0                                                      | 1        | 247.5          | 0.70    | 1.2          | 0.2865     | 0.17      | 1.3          | 1.061 | -- |
| BCI | \(e^{a_o}_{c_s} = e^{a_o}_{ad. s}\) | Cl_{pr}                     | Actual val. [mm]                                      | Cl_{f}   | Actual val. [mm] | Cl_{f}   | \(k_{f}\) (Max) |
| 4   | \(0.020\)                         | \(0.017\)                   | 0                                                      | 1        | 623            | 0.23    | 1.2          | 0.3678     | 0.26      | 1.3          | 0.614 | -- |
| 5   | \(0.020\)                         | \(0.017\)                   | 0                                                      | 1        | 311.5          | 0.62    | 1.2          | 0.4114     | 0.31      | 1.3          | 1.147 | -- |
| 6   | \(0.017\)                         | \(0.017\)                   | 1                                                      | 1        | 51.9           | 0.95    | 1.2          | 0.9331     | 0.99      | 1.3          | 3.427 | Opt. BCII |
| BCI | \(e^{a_o}_{c_s} = e^{a_o}_{ad. s}\) | Cl_{pr}                     | Actual val. [mm]                                      | Cl_{f}   | Actual val. [mm] | Cl_{f}   | \(k_{f}\) (Max) |
| 7   | \(0.010\)                         | \(0.012\)                   | 0                                                      | 2        | 51.75          | 0.95    | 1.2          | 0.3678     | 0.26      | 1.3          | 1.678 | -- |
| 8   | \(0.010\)                         | \(0.012\)                   | 0                                                      | 1        | 12.3           | 1       | 1.2          | 0.979      | 0.97      | 1.3          | 3.461 | Opt. BCIII |
| BFIV| \(\nabla_{3}^{n}\)                |                            |                                                         |          | 200.62         | 0.76    | 1.2          | 0.999      | 1         | 1.3          | 3.212 | Opt. BCIV |
| 9   | \(\nabla_{3}^{n}\)                |                            |                                                         |          | 200.62         | 0.76    | 1.2          | 0.999      | 1         | 1.3          | 3.212 | Opt. BCIV |

Calculation of coefficients of importance for the cost criterion (C_{c})

By using the interpolation method for the minimizing feature values are determined with relation (3):
C_{c}^{X_{11}} = \frac{807 - 346.5}{807 - 12.3} = 0.57; C_{c}^{X_{12}} = \frac{807 - 807}{807 - 12.3} = 0; C_{c}^{X_{13}} = \frac{807 - 247.5}{807 - 12.3} = 0.70

For the other structures, the values calculated similarly are:
C_{c}^{X_{21}} = 0.23; C_{c}^{X_{22}} = 0.62; C_{c}^{X_{23}} = 0.95; C_{c}^{X_{24}} = 0.95; C_{c}^{X_{25}} = 1; C_{c}^{X_{26}} = 0.76; C_{c}^{X_{27}} = 0.76.

Calculation of coefficients of importance for the flexibility criterion (C_{f})

For C_{f} it is considered that maximum flexibility has value 1, and the least flexible constructive variant has value zero. The coefficient of importance of flexibility C_{f} is established for the maximizing feature with the relation from this paper (E_{05}) for X_{ij} analyzed structures:
C_{f}^{X_{11}} = \frac{0.3678 - 0.1353}{0.999 - 0.1353} = 0.26
Similarly there are determined and introduced in Table 1 $C_l^{X_{ij}}$ for the other $X_{ij}$ structures, with the following values: $C_l^{X_{12}} = 0; C_l^{X_{12}} = 0.17; C_l^{X_{23}} = 0.31; C_l^{X_{23}} = 0.99; C_l^{X_{23}} = 0.26; C_l^{X_{23}} = 0.97; C_l^{X_{23}} = 1; C_l^{X_{23}} = 1$

In order to prioritize criteria, from an importance viewpoint, the correction coefficients for precision $k_r^{pr} = 1$, costs $k_r^{c} = 1.2$, and flexibility $k_r^{f} = 1.3$ are established.

E07 Selecting the construction variants of the device

Method 1: The optimal variant to construct the control device ($VOC_{DC}^1$) is a combination of structures which meet the condition locally optimal as max $\Sigma CI$ of BCI, ..., BFV:

\[
\Sigma CI^{X_{11}} = Cl_{pr}^r \cdot k_r^{pr} + Cl_{c}^r \cdot k_r^{c} + Cl_{f}^r \cdot k_r^{f} = 0.2 \cdot 1.0 + 0.57 \cdot 1.2 + 0.26 \cdot 1.3 = 1.222 \Rightarrow \Sigma CI^{X_{11}} = 1.222
\]

By proceeding similarly it is obtained:

\[
\begin{align*}
\Sigma CI^{X_{12}} &= 1, \\
\Sigma BCI^{X_{13}} &= 1.061, \\
\Sigma BCI^{X_{22}} &= 0.614, \\
\Sigma BCI^{X_{23}} &= 1.147, \\
\Sigma BCII^{X_{24}} &= 3.427, \\
\Sigma BCII^{X_{25}} &= 3.212, \\
\Sigma BCFV^{X_{26}} &= 3.212.
\end{align*}
\]

Method 2: The optimal variant of the control device ($VOC_{DC}^2$) is a combination of structures which meet condition $MaxV_{BCI}$, ..., $MaxV_{BFV}$ from the calculation relation (5):

\[
MaxV_{BCI} [CI_{pr}^{X_{11}} \cdot k_r^{pr} \cdot Cl_{c}^{X_{11}} \cdot k_r^{c} + CI_{f}^{X_{11}} \cdot k_r^{f}]; ... ; Cl_{pr}^{X_{12}} \cdot k_r^{pr} \cdot Cl_{c}^{X_{12}} \cdot k_r^{c} + Cl_{f}^{X_{12}} \cdot k_r^{f}]; ... ; Cl_{pr}^{X_{23}} \cdot k_r^{pr} \cdot Cl_{c}^{X_{23}} \cdot k_r^{c} + Cl_{f}^{X_{23}} \cdot k_r^{f}]
\]

\[
\begin{align*}
MaxV_{BCI}[0.2 \cdot 1(0.57 \cdot 1.2 + 0.36 \cdot 1.3) \cdot 1 \cdot 1(0.12 + 0.13 \cdot 1.3) \cdot 0 \cdot 1(0.7 \cdot 1.2 + 0.21 \cdot 1.3)] \Rightarrow \\
MaxV_{BCI}(0.221;0.169;0) \Rightarrow MaxV_{BCI} = 0.221
\end{align*}
\]

By proceeding similarly for the other groups it is obtained:

Max$_{BCI}$ = 1.47; Max$_{BCII}$ = 2.461; Max$_{BFIV}$ = 2.199; Max$_{BFV}$ = 2.199

E08 Establishing the optimal variants to construct the control device

Method 1:

\[VOC_{DC}^1 = OptimBCI + OptimBCII + OptimBCIII + OptimBFIV + OptimBFV \]

It results: $VOC_{DC}^1 = X_{11} + X_{23} + X_{32} + X_{41} + X_{51}$

Method 2:

The optimal variant to construct the control device is a combination of structures which meet the condition of maximum of coefficients of importance from relation (7) of analyzed variants:

\[VOC_{DC}^2 = MaxV_{BCI} + MaxV_{BCII} + MaxV_{BCIII} + MaxV_{BFIV} + MaxV_{BFV} \]

It results: $VOC_{DC}^2 = X_{11} + X_{23} + X_{32} + X_{41} + X_{51}$

3. Construction of the control device

For the construction of the control device and any other type of device, choose or design elements or subassemblies of the orientation and fixing system of the semi-finished product, bodies, connecting and guiding elements with features and functions identical to those of $VOC_{DC}^2$ structures. The constructive solution can be made in the special variant or from modular elements depending on the size of the manufacturing series and the optimization criteria chosen. In this case study the structures $X_{11}, X_{23}, X_{32}, X_{41}, X_{51}$ are found in the overall drawing of the device, in Figure 6.

The construction, configuration and working method with this device are atypical because some of the main and mandatory orientation elements do not allow the access of the control system to the surfaces to be measured.

For this reason it is necessary for the optimization algorithm to add, as a further conditioning, a planar pre-orientation base (11) and a planar substitution base (10) to the existing BCI, ..., BFV, and the sequence of work phase to be the following:

- Place the semi-finished product on the planar pre-orientation base of the support dowels 11, the short prism 1 and the support dowel 5 under its own weight and elastic tightening of the support 9 with self-positioning and subsequent blocking;
The three elements 4 of the main orientation base are rotated and blocked in the working position;

- The movable element of the support 12 with self-positioning is brought into contact with the lower part of the semi-finished product, which rises from the planar pre-orientation base 11 and is placed on the main planar base 4, and then blocks;
- In contact with some surfaces of the part to be measured, located below the level of the main positioning base, the three self-positioning supports 10 and the conical movable elements, block afterwards, thus establishing a planar substitution base;
- The three movable elements 4 rotate to allow the access of the control system to check the quotations and measurement conditions, while the semi-finished product keeps its main orientation and fixing unaltered.

Figure 6. Overall drawing of the device to control inaccessible surfaces

4. Conclusions
The development of manufacturing systems through mathematical modelling, of construction and devices operation, of technological equipment in general is certainly very useful and much more economical than many costly and long lasting practical attempts to establish the optimal solution.

This paper presents a case study that confirms that not only the original optimization method but also the proposed calculation methods provide a reliable optimization solution for rational device construction.

References
[1] Brăgaru A, Picoș C and Ivan NV 1996 Optimization of processes and technological equipment (Bucarest: Didactic and Pedagogic Publishing Bucarest)
[2] Ivan NV, Păunescu T, Udriou R, Ivan MC, Găvruș C and Pescaru R 2010 Machine Building Technology. Theory and innovative approaches (Brașov: Transilvania University of Brașov)
[3] Li B and Melkote SN 2001 Int. J. Adv. Manuf. Tech. 17 104-113
[4] Vasii Roșculeț S, Gojinethechi N, Andronic C, Șelariu M and Gherghel I 1982 Device design (Bucarest: Didactic and Pedagogic Publishing Bucarest)
[5] Iordache DM, Rizea AD, Costea A, Nițu EL and Babă A 2017 Method for optimization of the orientation and fixing system of workpiece for the construction of control devices MATEC Web of Conferences 112 06003 (2017)
[6] Costea A and Rachieru N 2005 Flexibility and performance of processing equipment (Bucarest: BREN Publishing House)
[7] Abrudan I 1996 Flexible Manufacturing Systems. Design and management concepts (Cluj-Napoca: Dacia Publishing).
[8] Boldur Gh 1973 The complex foundation of the economic decision-making process (Bucarest: Scientific Publishing House)