CONSTRUCTIONAL OPTIMIZATION OF THE BEARINGS OF A MODULAR BORING JIG BY DECISIONAL SIMULATION

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Abstract: *The establishment of the optimum blank's Fixing and Orienting Basis System is an important step in contriving a manufacturing device. In the case of a modular device, the optimum orientation alternative is difficult to be determined, because of, on the one hand, the huge number of constructional types of the bearings, and, on the other hand, because of the multiple economical criteria which can be taken into consideration. This work summarizes an application concerning the use of the multi-criteria decisional analysis for establishing the optimum orienting alternative of the blank, for a drilling operation performed with a multi-tool modular device and the constructional optimization of this variant using the linear programming method.*

Keywords: fixing and Orienting Basis System, the Onicescu method

INTRODUCTION

The establishment of the optimum blank's Fixing and Orienting Basis System is an important step in contriving a manufacturing device.
The optimum orienting diagram is determined by keeping the economical and technical criterion. The technical criterion takes into account the accuracy of processing, while the economical criterion assesses the keep of several conditions, mainly, concerning the simplicity of the structure, convenience in exploitation / use, productivity and cost.
The authors' personal research concerning the conceiving and the production of a Modular Device for the Processing of the Multi-tool Drill, emphasized the fact that, for a modular device, the optimum orienting variant is difficult to be determined because, on the one hand, of the big number of constructive types of the bearings, and, on the other hand, because of the multiple economical criteria which can be taken into consideration.
That is why it is to be noticed the use of some decisional analysis techniques and methods, to assure the scientific basement of the adopted solutions.
The present work is an application concerning the use of the multi-criteria decisional analysis for establishing the optimum orienting alternative of the blank in the case of a processing operation performed with DMPMG and the constructive optimization of this variant using the linear programming method.

THE ESTABLISHMENT OF THE OPTIMUM ORIENTING ALTERNATIVE

For the multiple-tool drilling operation for which the modular device is designed, there were performed, during the analysis, the following steps from the optimum SBOF establishing methodology [1]:

1. The determination of the measurements to be achieved on the piece while processing and of the mark basis system (MBC);
2. The determination of the technological basis system (TBS);
3. The determination of the orientation basis systems and of the orientation elements that can be used (fig.1);
4. The calculation of the allowable errors of the marks to be achieved on the piece during the processing;
5. The calculation of the orientation errors for each orienting variant.

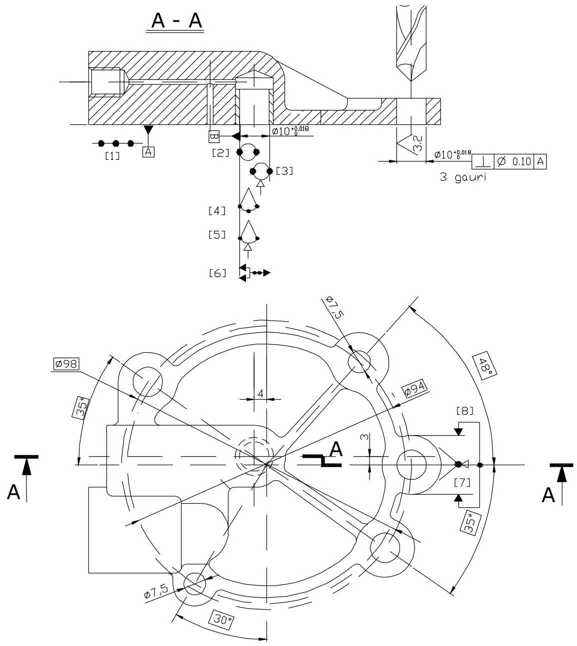

Fig. 1 The orienting basis system

The results is 10 orienting diagrams technically possible, noted V1, V2,...V10 and represented, with the suitable orienting elements, in table 1.
One must choose, on economical criteria, the optimum orienting diagram.
Knowing the variants submitted to analysis one can determine more decisional criteria, for which one can tell the consequences, the decisional situation is defined under certain conditions. Besides, the criteria taken into consideration can be sorted hierarchically by adding several important coefficients, included in an interval, as for example [0,1].

Table1. Technically possible orienting diagrams

The orienting variant	The orienting elements used		
V1			
V2			
V3			
V4			
V5			
V6			
V7			
V8			
V9			
V10			

The multiple-criteria rationalization under **certainty conditions** can be done by many methods: the global utility method, the Electre method, the Onicescu method, the decisional table.
For the given problem one will use the **Onicescu method** – 2nd version, where the importance coefficients allotted to these criteria are differentiate, considered to be a very efficient one and easy to be applied.

The decision criteria applied to the technically possible orienting variants and the importance coefficients allotted to each criterion are presented in table 2.

Table 2. Decision criteria and their importance

The decision criterion		Importance coefficient, K_j
Cod	Name	
C1	Complexity degree	0,25
C2	Constructional accuracy	0,25
C3	Soft assembly	0,15
C4	High reliability	0,20
C5	Convenience in use	0,15

One appraises the level where each variant satisfies a criterion, by comparison, by balanced results following the scale below:

Satisfaction level	Weight
Extremely low	1
Very low	2
Low	3
Easy - reduced	4
Medium	5
Little high	6
High	7
Very high	8
Extremely high	9

In the appraisal of the consequences of each criterion one has taken into account the type of the bearing elements that compose each orienting diagram (rigid, mobile, self aligning), the number of the same type elements from each diagram) and the constructive/ constructional variants of the bearings (cylindrical bolt, mobile bolt, prism, self aligning mechanism).

The Onicescu method supposes the following of the steps below:

a. Determination of the A matrix, of the decisional consequences;
b. Ordering the variants, for each criterion, decreasing the consequences (matrix B);

$$A = \begin{array}{c|ccccc} & C1 & C2 & C3 & C4 & C5 \\ \hline V1 & 8 & 8 & 8 & 4 & 6 \\ V2 & 7 & 7 & 7 & 5 & 5 \\ V3 & 6 & 6 & 6 & 6 & 3 \\ V4 & 5 & 5 & 6 & 6 & 4 \\ V5 & 7 & 8 & 8 & 4 & 6 \\ V6 & 6 & 7 & 7 & 5 & 5 \\ V7 & 5 & 6 & 5 & 7 & 3 \\ V8 & 4 & 6 & 6 & 6 & 4 \\ V9 & 4 & 6 & 6 & 6 & 4 \\ V10 & 3 & 4 & 4 & 8 & 3 \end{array} \qquad B = \begin{array}{|ccccc|} C1 & C2 & C3 & C4 & C5 \\ \hline V1 & V1 & V1 & V10 & V1 \\ V2 & V5 & V5 & V7 & V5 \\ V5 & V2 & V2 & V3 & V2 \\ V3 & V6 & V6 & V4 & V6 \\ V6 & V3 & V3 & V8 & V4 \\ V4 & V7 & V4 & V9 & V8 \\ V7 & V8 & V8 & V2 & V9 \\ V8 & V9 & V9 & V6 & V3 \\ V9 & V4 & V7 & V1 & V7 \\ V10 & V10 & V10 & V5 & V10 \end{array}$$

c. Determination of the matrix C, of the places busy with variants within each criterion;

$$C = \begin{array}{c|ccccc} & C1 & C2 & C3 & C4 & C5 \\ \hline V1 & 1 & 1 & 1 & 9 & 1 \\ V2 & 2 & 3 & 3 & 7 & 3 \\ V3 & 4 & 5 & 5 & 3 & 8 \\ V4 & 6 & 9 & 6 & 4 & 5 \\ V5 & 3 & 2 & 2 & 10 & 2 \\ V6 & 5 & 4 & 4 & 8 & 4 \\ V7 & 7 & 6 & 9 & 2 & 9 \\ V8 & 8 & 7 & 7 & 5 & 6 \\ V9 & 9 & 8 & 8 & 6 & 7 \\ V10 & 10 & 10 & 10 & 1 & 10 \end{array}$$

d. Allotment of the importance coefficients to the decision criteria, differentiated by the relation:

$$p = \frac{1}{2^k} \qquad (1)$$

where k = 1 for the most important criterion, k = 2 for the 2^{nd} most important criterion a.s.o.

According to the importance coefficients from table 1, it results:

$$p_1 = \frac{1}{2},\ p_2 = \frac{1}{2},\ p_3 = \frac{1}{2^3},\ p_4 = \frac{1}{2^2},\ p_5 = \frac{1}{2^3} \qquad (2)$$

e. The hierarchically sorting of the variants according to an aggregation function of the form: $f \div V \to R_+$, defined:

$$f(V_i) = \sum_{j=1}^{n} p_j \div 2^{loc(V_i, C_j)} \qquad (3)$$

where V_i, $i = 1, 2, ..., m$ are the variants to be optimized, C_j, $j = 1, 2, ..., n$ are the decision criteria, and loc (V_i, C_j) is the place occupied by the alternate i within the criterion j.
The variants' hierarchy is given by the descending values of the aggregation function. So that:

$$\begin{aligned}
f(V1) &= \frac{1}{2}\cdot\frac{1}{2} + \frac{1}{2}\cdot\frac{1}{2} + \frac{1}{2^3}\cdot\frac{1}{2} + \frac{1}{2^2}\cdot\frac{1}{2^9} + \frac{1}{2^3}\cdot\frac{1}{2} = 0{,}56\\
f(V2) &= \frac{1}{2}\cdot\frac{1}{2^2} + \frac{1}{2}\cdot\frac{1}{2^3} + \frac{1}{2^3}\cdot\frac{1}{2^3} + \frac{1}{2^2}\cdot\frac{1}{2^7} + \frac{1}{2^3}\cdot\frac{1}{2^3} = 0{,}13\\
f(V3) &= \frac{1}{2}\cdot\frac{1}{2^4} + \frac{1}{2}\cdot\frac{1}{2^5} + \frac{1}{2^3}\cdot\frac{1}{2^3} + \frac{1}{2^2}\cdot\frac{1}{2^7} + \frac{1}{2^3}\cdot\frac{1}{2^3} = 0{,}14\\
f(V4) &= \frac{1}{2}\cdot\frac{1}{2^6} + \frac{1}{2}\cdot\frac{1}{2^9} + \frac{1}{2^3}\cdot\frac{1}{2^6} + \frac{1}{2^2}\cdot\frac{1}{2^4} + \frac{1}{2^3}\cdot\frac{1}{2^5} = 0{,}03\\
f(V5) &= \frac{1}{2}\cdot\frac{1}{2^3} + \frac{1}{2}\cdot\frac{1}{2^2} + \frac{1}{2^3}\cdot\frac{1}{2^2} + \frac{1}{2^2}\cdot\frac{1}{2^{10}} + \frac{1}{2^3}\cdot\frac{1}{2^2} = 0{,}22\\
f(V6) &= \frac{1}{2}\cdot\frac{1}{2^5} + \frac{1}{2}\cdot\frac{1}{2^4} + \frac{1}{2^3}\cdot\frac{1}{2^4} + \frac{1}{2^2}\cdot\frac{1}{2^8} + \frac{1}{2^3}\cdot\frac{1}{2^4} = 0{,}06\\
f(V7) &= \frac{1}{2}\cdot\frac{1}{2^7} + \frac{1}{2}\cdot\frac{1}{2^6} + \frac{1}{2^3}\cdot\frac{1}{2^9} + \frac{1}{2^2}\cdot\frac{1}{2^2} + \frac{1}{2^3}\cdot\frac{1}{2^9} = 0{,}07\\
f(V8) &= \frac{1}{2}\cdot\frac{1}{2^8} + \frac{1}{2}\cdot\frac{1}{2^7} + \frac{1}{2^3}\cdot\frac{1}{2^7} + \frac{1}{2^2}\cdot\frac{1}{2^2} + \frac{1}{2^3}\cdot\frac{1}{2^9} = 0{,}08\\
f(V9) &= \frac{1}{2}\cdot\frac{1}{2^9} + \frac{1}{2}\cdot\frac{1}{2^8} + \frac{1}{2^3}\cdot\frac{1}{2^8} + \frac{1}{2^2}\cdot\frac{1}{2^6} + \frac{1}{2^3}\cdot\frac{1}{2^7} = 0{,}006\\
f(V10) &= \frac{1}{2}\cdot\frac{1}{2^{10}} + \frac{1}{2}\cdot\frac{1}{2^{10}} + \frac{1}{2^3}\cdot\frac{1}{2^{10}} + \frac{1}{2^2}\cdot\frac{1}{2} + \frac{1}{2^3}\cdot\frac{1}{2^{10}} = 0{,}12
\end{aligned} \qquad (4)$$

There results that the variant 1 (, ,), which has the biggest value of the aggregation function, is the optimum fastening and orienting scheme, by economical and technical reasons.

CONSTRUCTIONAL OPTIMIZATION OF THE OPTIMUM FASTENING AND ORIENTING SCHEME

The materialization of the optimum fastening and orienting scheme presumes the analysis of the constructive types of bearings, having the same functions that form the optimum orienting variant and the choosing of the most rational solution.
The optimization can be accomplished using the linear programming method, in binary variable, discussing about accepting or denying several constructive types of bearings.
The object minimizing function is represented by the orienting scheme cost, and as restrictions it is considered that the orienting accuracy of the bearing like modular element, appraised by the constructional orienting error, ε and the bearing's reliability, f.
The data concerning the orienting accuracy have been taken from the woks [1] and [2], and in establishing the reliability coefficients, appreciated on a scale from 1 to 5, one has taken into account the capacity of the bearing to keep in time, its functioning.
It is considered that the following constructive variants of the bearings, which made up the optimum fixing and orienting scheme:

- For the plan bearing :

x_{11} – plane surface materialized by tips;

x_{12} – plane surface materialized by tongues / studs; - for the rigid bolt:
x_{21} – lis bolt, mounted directly into the engine's body;
x_{22} – lis bolt with a middle-fit element;
x_{23} – lis bolt with a wear bush; For the mobile prism:
x_{31} – mobile prism manipulated with dowel/bolt;
x_{32} – self-braking prism.

If we note: ε_{ij} - the constructive orienting errors of the analyzed bearings de, f_{ij} – the reliability coefficients, c_{ij} – the cost of each type of bearing, and $\varepsilon_{adm\ 1,2,3}$ - the allowable orienting error for the sizes to be achieved, the mathematical model of the linear programming problem has the form presented in the relations (5).

The values of the coefficients from the mathematical model are presented in table 3.

For solving this, one has use the Linear module and Integer Programming of the soft Win QSB. The solution of the problem (table 5) is presented in the initial data table (table 4) .

It is to be noticed that the optimum constructional solution, which assures the minimum cost, requires the use of the following types of bearings: the side plates, for the materialization of the plane surface, the lis bolt mounted into the middle-fit element and the mobile prism manipulated with dowel/bolt.

$$
\begin{aligned}
&\min C = c_{11}x_{11} + c_{12}x_{12} + c_{21}x_{21} + c_{22}x_{22} + c_{23}x_{23} + c_{31}x_{31} + c_{32}x_{32} \\
&\varepsilon_{11}x_{11} + \varepsilon_{12}x_{12} \le \varepsilon_{ad1} \\
&f_{11}x_{11} + f_{12}x_{12} \ge 1 \\
&x_{11} + x_{12} = 1 \\
&\varepsilon_{21}x_{21} + \varepsilon_{22}x_{22} + \varepsilon_{23}x_{23} \le \varepsilon_{ad2} \\
&f_{21}x_{21} + f_{22}x_{22} + f_{23}x_{23} \ge 1 \\
&x_{21} + x_{22} + x_{23} = 1 \\
&\varepsilon_{31}x_{31} + \varepsilon_{32}x_{32} \le \varepsilon_{ad3} \\
&f_{31}x_{31} + f_{32}x_{32} \ge 1 \\
&x_{31} + x_{32} = 1
\end{aligned}
\tag{5}
$$

x_{11}, x_{12}, x_{21}, x_{22}, x_{23}, x_{31}, x_{32} are binary variables.

Table 3. The mathematical model coefficients

N° crt.	Bearing code	The coefficients value			
		ε_{ij}	f_{ij}	c_{ij}	ε_{adm}
1	x_{11}	0,015	1	23	0,033
2	x_{12}	0,015	1	36	
3	x_{21}	0,038	1	117	0,06
4	x_{22}	0,044	2	105	
5	x_{23}	0,028	3	139	
6	x_{31}	0,061	4	239	0,33
7	x_{32}	0,021	5	250	

Table 4. Basic data/ (base data/ initial data) matrix

Results Utilities Window WinQSB Help

Variable -->	X11	X12	X21	X22	X23	X91	X92	Direction	R. H. S.
Minimize	23	36	117	105	129	239	250		
C1	0.015	0.015						<=	0.033
C2	1	2						>=	1
C3	1	1						=	1
C4			0.048	0.034	0.028			<=	0,06
C5			1	2	3			>=	1
C6			1	1	1			=	1
C7						0.061	0.021	<=	0.33
C8						4	5	>=	1
C9						1	1	=	1
LowerBound	0	0	0	0	0	0	0		
UpperBound	1	1	1	1	1	1	1		
VariableType	Binary	Binary	Binary	Binary	Binary	Binary	Binary		

Table 5. The optimum solution of the mathematical model

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	Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
1	X11	1,0000	23,0000	23,0000	0	basic	-M	36,0000
2	X12	0	36,0000	0	0	basic	23,0000	M
3	X21	0	117,0000	0	12,0000	at bound	105,0000	M
4	X22	1,0000	105,0000	105,0000	0	basic	-M	117,0000
5	X23	0	129,0000	0	24,0000	at bound	105,0000	M
6	X91	1,0000	239,0000	239,0000	0	basic	-M	250,0000
7	X92	0	250,0000	0	11,0000	at bound	239,0000	M
	Objective	Function	(Min.) =	367,0000				
	Constraint	Left Hand Side	Direction	Right Hand Side	Slack or Surplus	Shadow Price	Allowable Min. RHS	Allowable Max. RHS
1	C1	0,0150	<=	0,0330	0,0180	0	0,0150	M
2	C2	1,0000	>=	1,0000	0	13,0000	1,0000	2,0000
3	C3	1,0000	=	1,0000	0	10,0000	0,5000	1,0000
4	C4	0,0340	<=	6,0000	5,9660	0	0,0340	M
5	C5	2,0000	>=	1,0000	1,0000	0	-M	2,0000
6	C6	1,0000	=	1,0000	0	105,0000	0,5000	1,0000
7	C7	0,0610	<=	0,3300	0,2690	0	0,0610	M
8	C8	4,0000	>=	1,0000	3,0000	0	-M	4,0000
9	C9	1,0000	=	1,0000	0	239,0000	0,2500	1,0000

CONCLUSIONS

During the conceptual phase of a modular processing device, the establishment of the structure of its sub-systems is a decisional problem of a great importance.

The use of the scientifically optimizing methods leads to the rationalization of the choice and assures, to the highest degree, the respecting of the requirements accuracy, reliability, productivity, under the conditions of a special flexibility and of the manufacturing costs reduction.

In this work, it is developed an application of the use of Onicescu method, of the analysis of decisions under certainty conditions, for the establishment of the optimum orienting variant, in the case of a drilling operation performed with a multiple-tool modular device.

The result obtained by decisional simulation complies with theoretical principles, which are the basis of processing devices and offer the certitude of a rational choice, scientifically justified.

Besides, for a set of given basic data, it is suggested a linear programming mathematical model, in binary variables, whose optimum solution establishes the constructional type of the bearings that are to be used, for a minimum cost of the orienting variant.

The scientifically method optimization results are used for the 3D simulation and are verified by simulating the device running / working.

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