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To cite this article: Y A Bondarenko and O V Bestuzheva 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **560** 012007

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Multicriterion optimization of processing of mill trunnion based on hierarchy analysis method

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Abstract. The article presents the choice of optimal method of treatment when restoring of mill trunnion based on hierarchy analysis method. The criterion for selecting optimal cutting conditions is synthesized and their relationship with processing parameters is described. Many alternatives for solving a multicriterion optimization problem are constructed, methods of processing with variable cutting conditions are proposed. Based on selected criteria, a subset of Pareto-optimal cutting conditions is found when restoring trunnion. The method of hierarchy analysis is presented as a multi-criteria method of decision-making using the algorithm for assessing the degree of consistency of paired comparison matrices. The applied method of expert evaluation selects the processing parameters with a decrease in the complexity of restoration work with preservation of quality of the processed surface of mill trunnion.

1. Introduction

In the production of building materials for grinding raw materials ball mills are used, the technical condition of which is characterized by long-term operation with significant wear of the predominantly mechanical part of rotating support parts – trunnion. On the working surface of the axis there are various defects that under the influence of dynamic loads contribute to the loss of performance and long downtime for repairs.

The add-on machine allows you to process trunnion mills at the site of operation [1]. The use of a rotary cutter allows you to improve the efficiency and productivity of the process, tool life with a high level of accuracy and quality of the machined surface. The decisive parameter in the rotational processing is the depth of the cut, the frequency of rotation of the axis, the speed of rotation of the workpiece and feed. At the same time, the ability to vary the cutting conditions allows you to achieve a given accuracy and quality of processing cylindrical surface and maintain high tool performance.

2. Materials and methods

To determine the handling of axles in the reconstruction work in the repair of mill trunnion based on hierarchy analysis method [2].

This method provides a systematic algorithm represents the components into a hierarchy to solve any problems. Decomposition of the problem into simple components and their subsequent processing by the judgment of decision makers, is made of paired comparisons. Judgments Express a numerical method, which shows the relative degree of interaction between the elements.



Method of analysis of hierarchies is a method of solving multicriteria problems with hierarchical structures in complex systems with tangible and intangible factors [3]. In contrast to the approach based on linear logic, in the method of hierarchy analysis used deductive logic, constructed by logic circuits to determine various conclusions. In addition, an approach based on logical circuits may not lead to the best solution, since in this case the possibility of accepting trade-offs between factors lying in different circuits of logical thinking may be lost.

Hierarchy is the main way in which a researcher can subdivide the entire set of studied data into clusters and subclusters [4]. The main task of the method of analyzing hierarchies is to evaluate the highest levels of the hierarchy, based on the interaction of various levels, and not on the direct dependence on the elements at these levels. The use of the method of analyzing hierarchies to determine the impact of innovative control actions (automated learning environment; interactive network interaction; guided self-cognitive activity; field session; automated document flow) on the result of training activities and the contribution of each control impact on the final result will improve the quality of training. The main task is to assess the significance of the considered control actions.

Decision-making processes in various fields of activity are in many respects similar. Therefore, a universal method of decision-making support is needed, consistent with the natural course of human thinking.

The economic, medical, political, social and managerial problems can often have several solutions. Often, when choosing one solution from among the many possible ones, a decision maker is guided only by intuitive ideas. As a result, the decision making is uncertain, which affects the quality of decisions made. Decision making is based on priority values.

Method of analysis of hierarchies currently has become a vast interdisciplinary branch of science with a strong mathematical and psychological studies and numerous applications [5].

The first stage in solving the problem is the formulation of goals and alternatives to achieve the goal (figure 1).

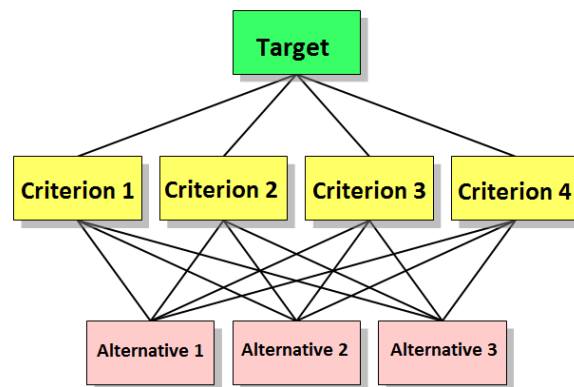


Figure 1. Hierarchical tree

The next step is to divide objectives into sub-objectives and criteria that implement the achievement of the goal. This process is called building a problem hierarchy tree [6]. The selected criteria are compared in pairs by a nine-point scale of relative importance.

For each element (in this case it is called a guided element), a square matrix is constructed, the dimension of which is equal to the number of lower level elements associated with the guided element.

After you define the preferences of each alternative to achieve the goal, given the degree of importance of each criterion.

Method of analysis of hierarchies is the main criterion of the quality of the expert's work – index of consistency, which gives information about the severity of consistency of expert judgments [7]. The lack of consistency can be a serious limiting factor for studies of certain problems.

To determine the degree of deviation of the matrix from the agreed, it is necessary to analyze the matrices of pairwise comparisons. Each matrix is estimated based on the index of consistency (IC) using the formula:

$$IC = \frac{\lambda_{max} - n}{n - 1},$$

where λ – an eigenvalue of values, n – the number of compared factors.

Coherence for random matrices of different order are given in table 1.

Table 1. Values of random consistency for matrices of different order

Matrix order	1	2	3	4	5	6	7	8	9	10
Degree of consistency (DC)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

If we divide IC into DC for the matrix of the same order, then we get the consistency relation (RC):

$$RC = \frac{IC}{DC}.$$

The quality of the expert is estimated by the value of the RC. To be acceptable, the value of the RC must be within 0.1 (10 %). In cases a complex system is considered and depends on a large number of factors, it is possible to set an upper limit of 20 %, but no more.

If the DC goes beyond these limits, then the results of the work of such experts are recommended to be excluded from consideration or to implement a procedure for adjusting judgments.

3. Determining the optimal method of treatment in the repair of mill trunnion based on hierarchy analysis method

Multipurpose optimization is to select, taking into account multiple criteria optimal decision from the set of alternatives that are combinations of characteristics of the processing trunnion. To solve the tasks were selected on the following criteria: the complexity of the restoration work, the axis processing time, the tool wear, the accuracy of the geometric parameters and the surface quality of the restored axis [6].

Some parameters and criteria are related by mathematical dependencies, but to determine the relationship of all factors is not a feasible task, due to the lack of data and the possibility of monitoring the results of the cutting process. Let us analyze the dependence of the criteria on the processing parameters.

Each criterion is characterized by a certain parameter: processing time – by the cutting speed, depending on the speed of rotation, tool wear – by the feed, complexity of restoration work is characterized by the two factors mentioned above, the accuracy of the geometric parameters – by the cut area of the layer, surface quality – by the roughness.

As the speed of rotation of the axis increases during repair, the machining time decreases, but the tool life is reduced, which leads to the rapid wear of the rotary cutter and the poor quality of the work surface. At the same time reducing the cutting speed leads to an increase in processing time. Depth of cut has a positive effect on the accuracy of geometrical parameters, but in this case the quality of the surface of the restored axis suffers [8].

At the same time, a reduction in the supply has a positive effect on the quality of the surface being restored with its increase, but the accuracy of the treated surface decreases [9].

The initial step of multi-criteria optimization is the search for a subset of non-dominated, that is, Pareto-optimal alternatives. Table 2 presents the methods of processing the trunnion with different characteristics of cut. In the course of the joint evaluation, the alternatives are narrowed according to all criteria, which leads to the following result - 9 Pareto-optimal methods were selected out of 15 processing methods.

Table 2. Characteristics of processing methods for the restoration of a trunnion

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Depth of cut, mm	0.5	1	1.5	2	2.5	0.5	1	1.5	2	2.5	0.5	1	1.5	2	2.5
Rotational speed, rpm	1	1	1	2	2	2	3	3	3	1	3	2	2	1	3
Cutting speed, m/min	5	5	5	10	10	10	15	15	15	20	20	20	25	25	25
Supply, mm/r	0.4	0.8	1.2	0.4	0.8	1.2	0.4	0.8	1.2	0.4	0.8	1.2	0.4	0.8	1.2
Pareto-optimal options (+)	-	+	+	-	+	-	-	+	+	-	-	+	+	+	+

In the next step the solution of a multicriteria problem uses the method of hierarchy analysis - a methodology for the selection the only alternative according to the criteria by using expert evaluations [10]. The result of data processing displays the priority of the compared processing methods. The process of phased selection of optimal processing parameters for the restoration of the axis is carried out by a specialist in the decision support system – MPRIORITY 1.0.

The choice of the only way to process the trunnion mill from Pareto-optimal subset is carried out by a structured three – level hierarchy: level 1 – target selection, level 2 – criteria selection, level 3- alternative selection. The hierarchy for determining the optimal way to handle the axle is shown in figure 2.

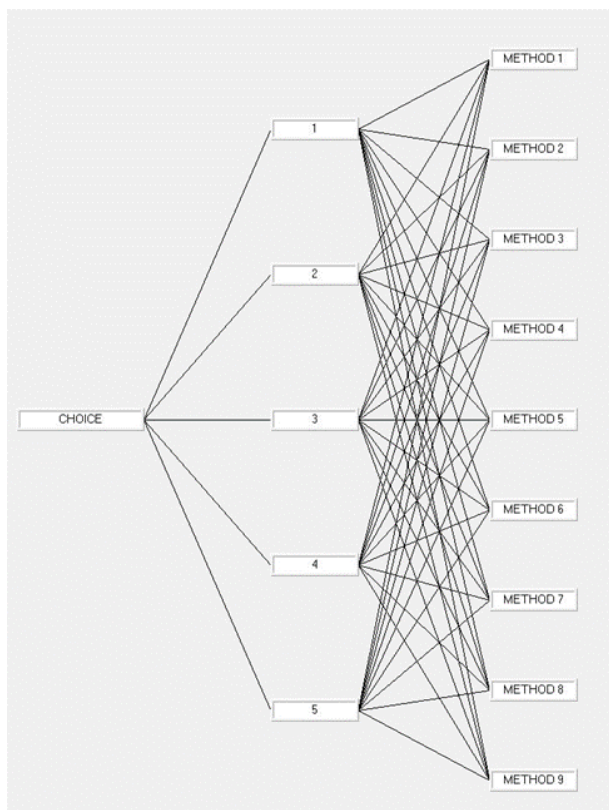


Figure 2. Built hierarchy to determine the optimal method of processing trunnion: 1 – the complexity of the work; 2 – processing time; 3 – tool wear; 4 – surface accuracy; 5 – roughness.

For further research using the method of pairwise comparisons using a scale of relative importance, an expert evaluates alternatives for each of the criteria: complexity of restoration work, axis processing time, tool wear, accuracy of geometric parameters and surface quality of the restored axis. Matrix comparison of the alternatives in relation to the criterion of “Laboriousness of the restoration work” obtained on the basis of expert data are presented in figure 3.

In doing so, MPRIORITY of the solution calculates the priority values, the degree of error, the consistency index and the consistency coefficient. In priority 0.2424, the alternative “METHOD 2” surpasses the other relatively labor-intensive restoration work.

The index value of the coherence matrix of pairwise comparisons is 0.0572 not exceeding the recommended value of 0.1. Analyzing the data presented, it can be concluded that the expert opinions are consistent and the results of the comparison methods are correct.

		1.	2.	3.	4.	5.	6.	7.	8.	9.	
1.	METHOD 1	1	1/7	1/3	1/7	3	1/5	1/7	1/5	1/3	0.027
2.	METHOD 2	7	1	5	2	7	1	3	2	5	0.2424
3.	METHOD 3	3	1/5	1	1/3	3	1/5	1/3	1/5	1	0.0488
4.	METHOD 4	7	1/2	3	1	5	1/3	1	1/2	3	0.12
5.	METHOD 5	1/3	1/7	1/3	1/5	1	1/5	1/3	1/3	1/5	0.0241
6.	METHOD 6	5	1	5	3	5	1	2	1	4	0.2031
7.	METHOD 7	7	1/3	3	1	3	1/2	1	1/3	2	0.1036
8.	METHOD 8	5	1/2	5	2	3	1	3	1	3	0.1721
9.	METHOD 9	3	1/5	1	1/3	5	1/4	1/2	1/3	1	0.0586
EI:		9.6645									
IC:		0.083									
RC:		0.0572									

Figure 3. Pairwise comparisons with respect to the criterion of “The complexity of the work”

Similarly, we construct a matrix comparison of alternatives for other criteria (figures 4-7), whose values have a high degree of uniformity and provide consistent information.

		1.	2.	3.	4.	5.	6.	7.	8.	9.	
1.	METHOD 1	1	1/5	1/3	1/5	1/3	1/3	1/3	1/3	1/5	0.0275
2.	METHOD 2	5	1	5	1	3	3	3	3	1/5	0.1689
3.	METHOD 3	3	1/5	1	1/5	1/3	1/3	1/3	1	1/5	0.0397
4.	METHOD 4	5	1	5	1	3	3	3	3	1/4	0.1731
5.	METHOD 5	3	1/3	3	1/3	1	1	1	1	1/5	0.0725
6.	METHOD 6	3	1/3	3	1/3	1	1	1	3	1/5	0.0819
7.	METHOD 7	3	1/3	3	1/3	1	1	1	1	1/5	0.0725
8.	METHOD 8	3	1/3	1	1/3	1	1/3	1	1	1	0.0679
9.	METHOD 9	5	5	5	4	5	5	5	1	1	0.2957
EI:		9.9696									
IC:		0.1212									
RC:		0.0835									

Figure 4. Pairwise comparisons with respect to the criterion of “Processing time”

As it can be seen from figure 4, the best method according to the criterion “Time of processing” is “METHOD 9”.

This is due to the high rotational speed and supply, while the cutting speed and the depth of cut are also of great importance. The consistency ratio in this case is 0.0835, which is valid when using the hierarchy analysis method.

		1.	2.	3.	4.	5.	6.	7.	8.	9.	
1.	METHOD 1	1	1/2	7	7	5	5	1/2	5	3	0.1949
2.	METHOD 2	2	1	7	7	5	5	1	5	5	0.2599
3.	METHOD 3	1/7	1/7	1	1	1/3	1/3	1/7	1/3	1/3	0.0245
4.	METHOD 4	1/7	1/7	1	1	1/3	1/3	1/7	1/3	1/3	0.0245
5.	METHOD 5	1/5	1/5	3	3	1	1	1/5	1	1	0.057
6.	METHOD 6	1/5	1/5	3	3	1	1	1/5	1	1	0.057
7.	METHOD 7	2	1	7	7	5	5	1	5	6	0.2652
8.	METHOD 8	1/5	1/5	3	3	1	1	1/5	1	3	0.0644
9.	METHOD 9	1/3	1/5	3	3	1	1	1/6	1/3	1	0.0523
EI:		9.3603									
IC:		0.045									
RC:		0.031									

Figure 5. Pairwise comparisons with respect to the criterion of “Tool wear”

Figure 5 shows pairwise comparisons with respect to the criterion of “Tool wear”. The value of the degree of consistency of this matrix in relation to the other criteria is the highest, equal to 0.031. This means an excellent job of an expert evaluating the alternatives by criteria.

Two methods of machining the trunnion according to the “Tool wear” criterion are optimal - “METHOD 2” with a priority value of 0.2599 and “METHOD 7” with a priority of 0.2652. This is due to the fact that small values of the cutting depth reduce tool wear, which is confirmed by theoretical knowledge.

		1.	2.	3.	4.	5.	6.	7.	8.	9.	
1.	METHOD 1	1	1	3	3	1	1	1	1	1	0.1308
2.	METHOD 2	1	1	5	5	1	1	1	1	2	0.1583
3.	METHOD 3	1/3	1/5	1	1	1	1	1/9	1	1	0.0594
4.	METHOD 4	1/3	1/5	1	1	1	1	1/9	1	1	0.0594
5.	METHOD 5	1	1	1	1	1	1	1	1	1	0.1025
6.	METHOD 6	1	1	1	1	1	1	1	1	1	0.1025
7.	METHOD 7	1	1	9	9	1	1	1	2	4	0.2104
8.	METHOD 8	1	1	1	1	1	1	1/2	1	1	0.0949
9.	METHOD 9	1	1/2	1	1	1	1	1/4	1	1	0.0813
EI:		9.8474									
IC:		0.1059									
RC:		0.073									

Figure 6. Pairwise comparisons with respect to the criterion of “Surface Accuracy”

Surface accuracy is a value that identifies the processing methods with the optimal values for the depth of cut, the rotational speed, the cutting speed and the feed in the complex.

Figure 6 shows pairwise comparisons with respect to the criterion of “Surface Accuracy”. This criterion identifies the following optimal methods: “METHOD 1” with a priority value of 0.1308, “METHOD 2” with a priority value of 0.1583, and “METHOD 7” with a priority value is 0.2104.

The ratio of the consistency of the matrix according to this criterion is 0.073. Thus, the matrix is consistent, since the value does not exceed 0.1.

		1.	2.	3.	4.	5.	6.	7.	8.	9.	
1.	METHOD 1	1	1/7	1/3	1/7	1/2	1/5	1/4	1/5	1/2	0.0243
2.	METHOD 2	7	1	3	1/2	5	2	3	3	3	0.1993
3.	METHOD 3	3	1/3	1	1/7	3	1/5	1/2	1/3	1/3	0.0454
4.	METHOD 4	7	2	7	1	5	2	5	3	4	0.2791
5.	METHOD 5	2	1/5	1/3	1/5	1	1/5	1/3	1/5	1/4	0.0292
6.	METHOD 6	5	1/2	5	1/2	5	1	3	2	2	0.1592
7.	METHOD 7	4	1/3	2	1/5	3	1/3	1	1/3	1/2	0.0629
8.	METHOD 8	5	1/3	3	1/3	5	1/2	3	1	2	0.1178
9.	METHOD 9	2	1/3	3	1/4	4	1/2	2	1/2	1	0.0824
EI:		9.5395									
IC:		0.0674									
RC:		0.0465									

Figure 7. Pairwise comparisons with respect to the criterion of “Roughness”

Roughness will be satisfactory with a reduced value of the cutting depth. This was the determining factor in prioritizing the way the spigot was machined.

Figure 7 shows the pairwise comparisons with respect to the criterion of “Roughness”. According to this criterion, consistency, as well as the above, is within the limits of permissible. The value of the relationship of consistency takes the value of 0.0465.

By the “Roughness” criterion, the “METHOD 4” is optimal with a priority value of 0.2791. It is also impossible to overlook the high priority of the processing method “METHOD 2” with a priority of 0.1993.

The next step of the hierarchy analysis method is to create a matrix of pairwise comparisons of criteria. In the constructed matrix, preference is given to the complexity of the work without neglecting the surface quality of the trunnion (figure 8).

		1.	2.	3.	4.	5.	
1.	1	1	3	5	3	3	0.4275
2.	2	1/3	1	3	3	1/3	0.1602
3.	3	1/5	1/3	1	1/3	1/3	0.06
4.	4	1/3	1/3	3	1	1/3	0.1032
5.	5	1/3	3	3	3	1	0.2487
EI:		5.3896					
IC:		0.0974					
RC:		0.0869					

Figure 8. Pairwise comparisons of the criteria

4. Research results

As a result, the evaluation of alternatives is the calculation of a rational processing method (figure 9).

According to the hierarchy analysis method, the best method for processing when restoring a pin is “METHOD 2”, the priority value is 0.2122. The processing parameters are characterized by the

following values: depth of cut - 1 mm, rotational speed - 1 rpm, cutting speed - 5 m / min, supply – 0.8 mm / r.

It should be added that “METHOD 4” and “METHOD 6” are also close to optimal.

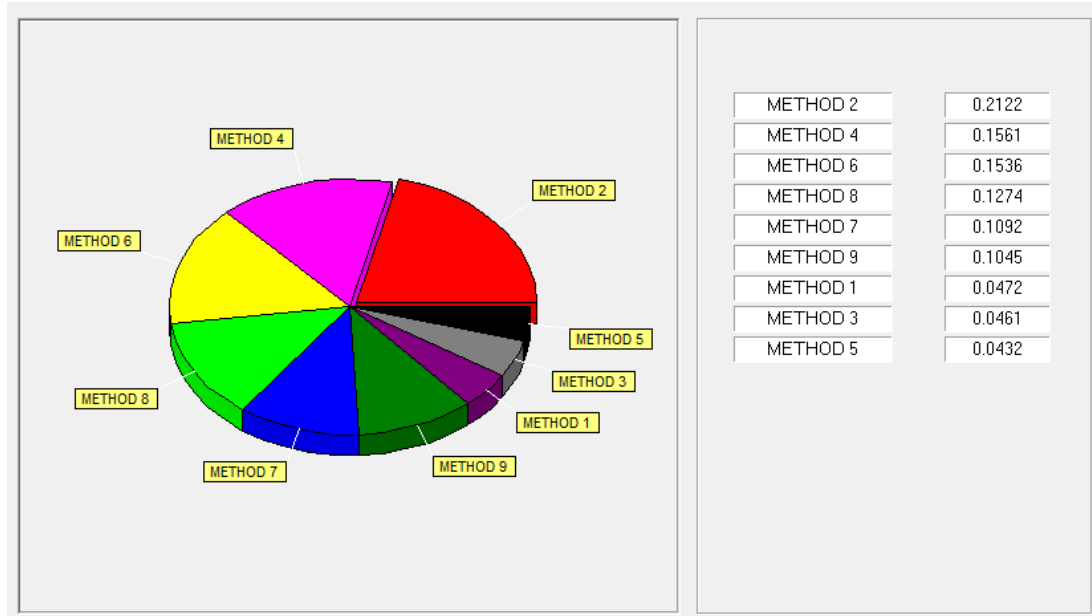


Figure 9. Priority Calculation Chart

5. Conclusion

The multi-criteria method of decision – i.e. performing the method of hierarchy analysis – is confirmed, the algorithm of estimation and increase of the degree of coherence of the matrices of pairwise comparison is applied. The proposed method of expert evaluation allows for the selection of process parameters to reduce the complexity of the work without neglecting the surface quality of the mill trunnion.

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