THE ANALYSIS OF THE TECHNICAL SYSTEMS' EVOLUTION

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Summary: *The paper presents the results of the analysis of vibroprotective devices' evolution with use of Analytic Hierarchy Process* (*AHP*). *A series of perspective technical solutions created in different moments of time was analyzed over the set of quality criteria being incorporated in the hierarchy. The marginal analysis of criteria has revealed criteria and their groups, which are the most important for perfection of pneumatic vibration isolators.*

1. Introduction

AHP/ANP, which was developed by T.L. Saaty (Saaty, 2001), gives a lot of opportunities for forecasting, that characterize a practical value of any decision-making method. One of such opportunities consists in using dynamic judgments as the elements of pair comparisons matrixes. We presented a software developed for support of decision-making on the basis AHP with dynamic judgments in the report in Proceedings of ISAHP'99 (Andreichicov and Andreichicova, 1999). This approach allows to predict and to trade-off the consequences of the decisions considered.

ANP is the other tool for constructing the forecasts. It enables to obtain the limit priorities of influence for all elements of a complex decision in conditions of mutual dependence and feedback. Application of this approach, as well as AHP with dynamic judgments to the problems of conceptual designing of technical objects, was considered in our paper at ISAHP'01 (Andreichicov and Andreichicova, 2001).

In the present paper we would like to show an application of AHP and marginal judgments to the problem of analysis of technical objects' evolution, which consists in revealing the tendencies of quality parameters' changes for devices with the certain functionality, and also in defining main directions of their further perfection.

The designing and the manufacturing of a competitive technical solutions need the analysis of development prospects for the devices being created. This problem is connected with the handling of large databases, where there is an information on devices of the considered class and close to it classes. The application of AHP for the information analysis enhances the creative labor efficiency at initial stages of designing. It is known from evolution theory, the information's value is determined by measure of its use. In this connection the software destined for the analysis of design databases enables to improve an information use and also gives an opportunity to discover a new knowledge.

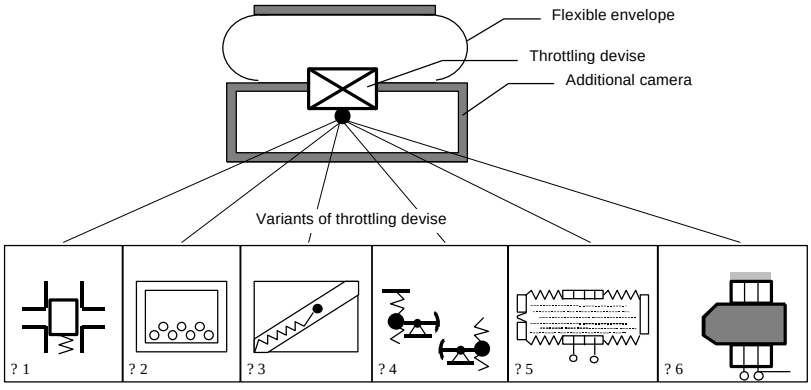
The analysis of technical systems (TS) with the same main function, which were created for a long period, enables to reveal criteria determining TS' evolution and its laws. The TS' evolution is considered as consecutive transformations series represented by an evolutionary chain or an evolutionary tree. Each previous technical solution is the prototype for an improvement at the next evolution stages. The certain stable changes of attributes (or criteria) during many generations of TS are named the laws of TS' development. The trends of functional, technological and economic properties of technical systems, if they are discovered, give to engineers a number of advantages in designing.

During an evolution, the improvements of TS by some quality criteria may be accompanied by significant deteriorations over other criteria. Therefore a multiple criteria analysis of inventions should be included in evolutionary chain. Application of AHP for evolutionary chain's analysis allows to find out the criteria importance trends and the tendencies of TS parameters' changing. Taking into account these tendencies, inventors can predict the properties of probable alternatives. When new technical systems (inventions) are being creating, there is an uncertainty in evaluating their properties. If some important parameters of TS deteriorate with time, the direction of TS perfection may be determined. Using marginal judgments, which allows to evaluate what properties should be improved the most, it is possible to find out preferable direction for TS perfection. After that one can choose the most suitable TS prototype. Thus, marginal analysis promotes to prevent mistakes, when rational variants of TS are being selected at early stage of designing for further design researches.

2. The Statement of the Task

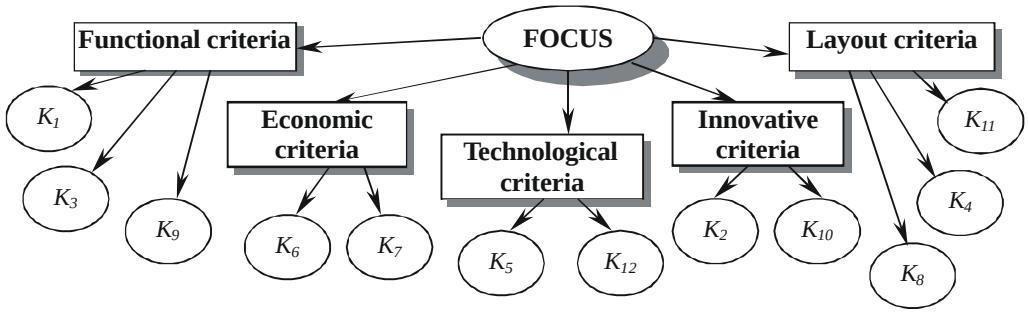
We have applied Analytic Hierarchy Process (AHP) for multiple-criteria analysis of vibroprotective devices' evolution, researching a number of technical solutions created at different moments of time. We researched the class of pneumatic devices with an adjustable throttle, which ensure vibrations damping by the certain law. The evolutionary chain included six air dampers A_i (i=1...6), protected by the USSR patents (figure 1). These alternatives were chosen as a result of the preliminary analysis of 102 patents, which were related to class examined.

Figure 1. The Principal Schemes of the Considered Air Dampers



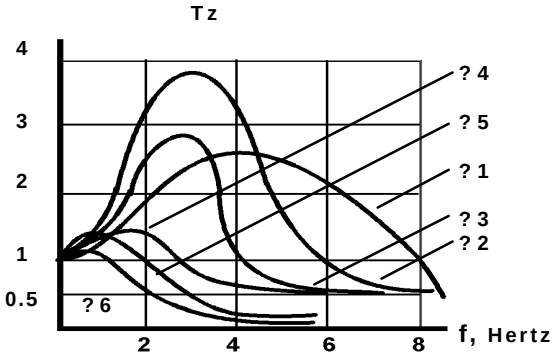
The main goal in this problem was formulated as follows: "To reveal the most perspective vibroprotective devices for perfection ". It was the focus of a hierarchy shown in the figure 2. The second hierarchy level contains the following criteria groups: Functional, Layout, Technological, Economic, Innovative. At the third level there are criteria connected with appropriate groups. The experts in the field of vibroprotection have assigned the following set of quality criteria, which are essential for evolution: K_1 – quality of the vibration damping; K_2 – patentability; K_3 – reliability; K_4 – opportunity for the system adaptability to various frequencies spectra; K_5 – constructional, technological and operational complexity of a system; K_6 – the cost of the device; K_7 – operational costs; K_8 – vibroprotection quality at various spatial orientation of the device; K_9 – opportunity for realization of the various damping laws; K_{10} – conformity of the system to the best analogues; K_{11} – compactness of the system; K_{12} – a need in new materials and technologies at the device creating.

Figure 2. A Hierarchy of Criteria for the Analysis of the Air Dampers' Evolution



The main functional criterion for development of air dampers is the amplitude-frequency characteristic of the transfer coefficient $?_z(f)$. The experimental amplitude-frequency characteristics of $?_z(f)$ for the considered devices are shown in a figure 3. The analysis of these characteristics reveals, that there is a stable tendency to improvement of quality of vibration damping, namely one can see that maximum of function $?_z(f)$, at passing from the previous device generation to the next, becomes less and is shifted to the range of lower frequencies (Andreichicov and Andreichicova, 1998).

Figure 3. Experimental Amplitude-Frequency Characteristics for the Transfer Coefficient $T_z(f)$ for Different Air Dampers

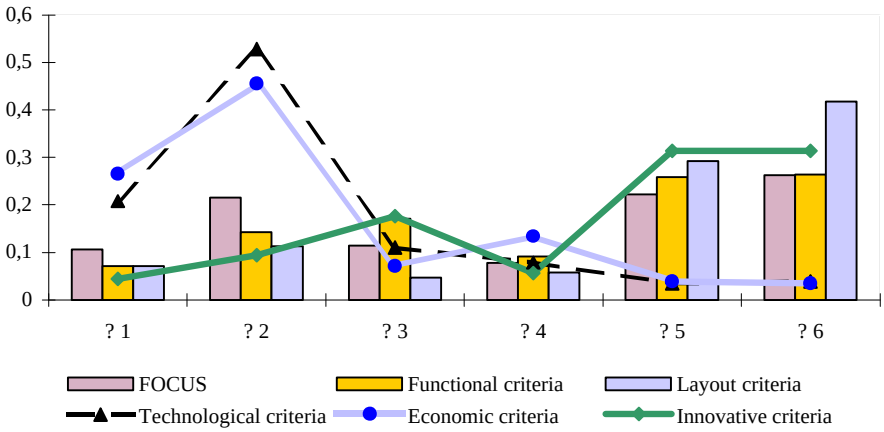


The experts have carried out pair comparisons of criteria groups, criteria and alternative devices. Expert judgments were used for calculating priorities of the alternatives concerning hierarchy focus and criteria groups, which are brought in table 1 and in figure 4.

Table 1. Priorities of Criteria Group and Air Dampers

		Alternatives					
	Criteria groups' weights	*?1*	*?2*	*?3*	*?4*	*?5*	*?6*
Focus		0,106	0,215	0,115	0,079	0,222	0,263
Functional criteria	0,348	0,071	0,143	0,172	0,057	0,259	0,264
Layout criteria	0,317	0,072	0,113	0,047	0,058	0,293	0,417
Technological criteria	0,156	0,208	0,528	0,11	0,057	0,039	0,035
Economical criteria	0,095	0,265	0,455	0,072	0,134	0,039	0,035
Innovative criteria	0,044	0,092	0,176	0,173	0,057	0,314	0,314

Figure 4. The Alternatives' Priorities by Focus and Criteria Groups



In a figure 4 one can see the following tendencies:

- General perfection of air dampers with time (Focus);
- Improvement of quality of vibration's damping (Functional);
- Refinement of layout parameters;
- Enhancement of innovation properties;
- Deterioration of economic and technological parameters.

3. The Marginal Analysis of Criteria

AHP is based on pair comparisons of the objects and on the calculation of eigenvectors for pair comparison matrixes, which are interpreted as vectors of priorities of considered objects (Saaty, 1994). The generalized priorities of the alternatives concerning a hierarchy focus are calculated as a linear additive convolution on the hierarchy. Note, that the alternatives are placed at the lowermost hierarchy level, that is not shown in a figure 3.

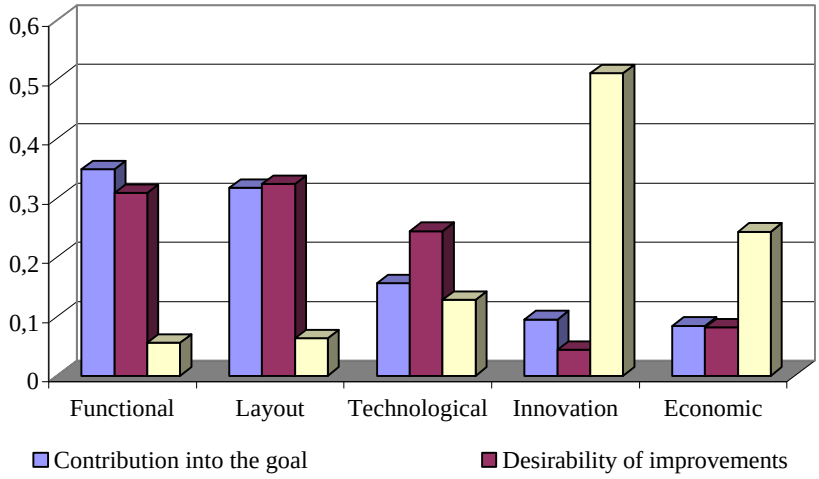
The priorities of alternatives relative to the elements of the second hierarchy level are shown in the figure 4, where one can see that Functional, Layout and Innovative properties improve in evolution process, but Economic and Technological criteria have a downtrend.

The analysis of air dampers by the Innovative criteria reveals an unordinary situation, when priority of later alternative $?_4$ is less than for previous prototype $?_3$. The alternatives' priorities concerning the hierarchy's focus have non-monotonic tendency, namely, the earlier designs are more effective as a whole than later inventions (A_2 better, than A_3 and A_4).

A useful instrument for the study of designs' evolution is marginal analysis carried out by means of AHP. The purpose of such analysis consists in revealing criteria, which are most desirable for the improvements in future. When experts were doing pair comparisons, we asked them a question: "Is an improvement by one criterion more preferably than commensurable improvement by another, and how much more preferably?" The priorities obtained allow to estimate an importance of criteria during evolution of devices considered. Improvement of a vibroprotective system's quality over one criterion is usually accompanied by a decreasing of its priorities over another. In this connection it is interesting to determine criteria, whose deterioration is admitted in a certain degree. The priorities of criteria groups concerning their contribution to main goal and marginal priorities corresponding to the desirability of improvement and admissibility of possible deterioration are shown in a figure 5. The groups are arranged in decreasing order of priorities concerning the hierarchy focus. The groups' marginal priorities obtained for improvements desirability have another ranking: the improvement of layout criteria is more important than improvement

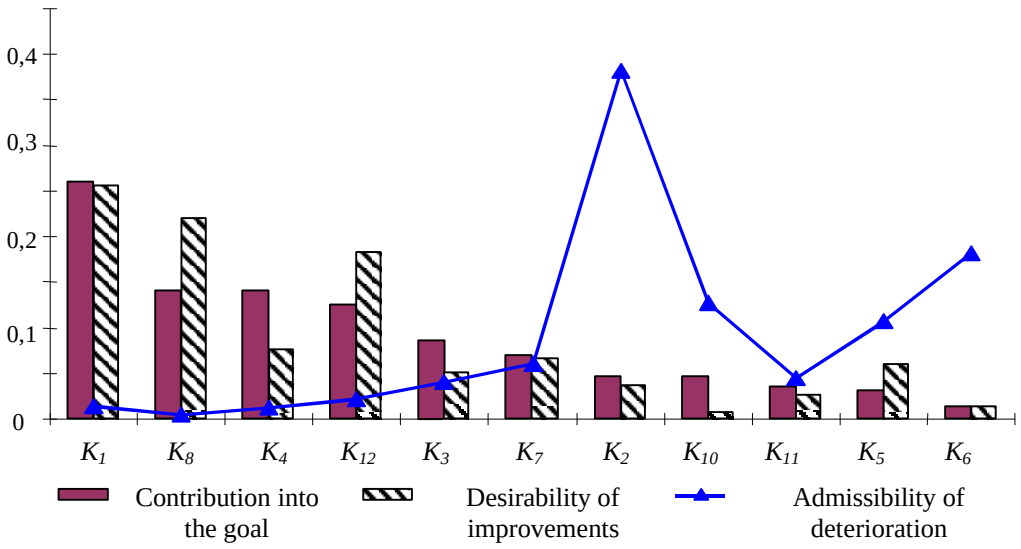
of functional parameters, and improvement of economic parameters is more important than improvement of innovation criteria. Functional, Layout and Innovative criteria are the most important ones for the progress. From the point of view of designer some deterioration of innovation and economic criteria are admitted, but the deterioration of functional and layout criteria are unacceptable. This result coincides with results of the analysis of evolution (figure 4).

Figure 5. The results of marginal analysis for criteria groups



The results of marginal analysis of criteria are brought in a figure 6. We can see that loss of vibroprotection quality (K_1), spatial orientation (K_8) and frequencies spectra reorganization (K_4) are unacceptable. The most urgent tasks are: the improvement of K_1, K_8 and adaptability to manufacture (K_{12}), then a decreasing of complexity (K_5), operational expenses (K_7), and increasing of reliability of systems (K_3) follow.

Figure 6. The results of marginal analysis for development criteria



It is easy to notice criteria, which are the most tolerant to deterioration in this case. It is patentability (K_2), then a cost (K_6), conformity to the best analogues (K_{10}), and complexity (K_5) follow.

4. Discussion

The outcomes obtained allow to discover TS properties, the most important for further perfection, and also the criteria groups, which strongly influence the parameters of systems examined. In this example the best prospects for development have air dampers with high values of priorities over Functional and Lay-out properties (A_5, A_6). Their perfection is connected with improvement of Economic and Technological parameters.

The evolution tendencies established give additional information promoting decision-making procedures in conceptual designing stage. Besides, these results help to determine directions for devices' perfection and to find out the contradictions between quality parameters.

The results of the marginal analysis of criteria have been completely proved by the analysis of evolution of the technical systems examined. Thus, the marginal analysis of criteria may be used as a tool for forecasting of development of TS from researched class. Such approach gives the opportunities to reduce the expenses of labor and time at the handling of patent information and also to frame hypotheses on devices' perfection in conceptual designing.

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