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AN ATTEMPT OF A COMPLEX DECISION SUPPORT IN SPRING DESIGN

Summary. In this paper strategies of solving the selection task in different stages of CAD of springs were presented. In the conceptual designing the selection of a variant of construction solution was based on the strategy of evaluation and selection. The following were discussed on the examples: (1) selection of a type of a single spring according to the selected aggregated criterion of evaluation, (2) selection of a conception of an assembly of springs according to the methods of the multi level interrelated criteria of evaluation. The single- and multicriterial problems of the detailed designing were shown of on examples of parametric optimization of assemblies of helical springs and of disc springs with or without the hierarchy of technical and economic criteria. The designers game on a set of feasible solutions of springs was presented, which was based on flexible changes of criteria and constraints with recognizing and selecting the solution space.

1. Introduction

The subject of this work is a method of supporting the decision process in CAD metal springs [1]. Examples of the application of the method have been systematized in coherent whole in which the subsequent strategies of the design process are illustrated by means of particular solution of design tasks. There are different strategies to solve these tasks. Strategies of the evaluation and selection; optimization; identification and subordination are used. In the strategy of evaluation and selection the following are establish: set of variants $A = \{a1, a2, \ldots, an\}$ set of evaluation criteria $K = \{k1, k2, \ldots, km\}$; selection criteria which subordinates evolution for every ordered pair $\langle ai, kj \rangle$ with respect to criterion "Fs" and method M of variant selection. In optimization strategy a formal model is constructed which contains: a set of decision variables, $Z = \{ Z1, Z2, \ldots, Zk\}$ a set of parameters $P = \{ p1, p2, \ldots, pn\}$ for given design context, constructions $R = \langle zn, pi \rangle$ and objective function F (criteria) subordinating a value to every variant which makes it possible to compare variant and to select on optimum variant.

The designed artifact may either be a single spring, a spring assembly with specific connection and switch "on"/"off" relations of the elements or a mechanism with elastic connectors.

The form of spring as it is constructed is adjusted to the functions which it fulfills and determined by a set of elementary construction features. Attention should be draw to the fact that in springs apart from geometric and material features typical for all the construction, the third type of features occurs. These feature are called loading once. Loading features express states and changes of the characteristic "deflection - force" (tolerances of forces and dimensions, correcting of force performance by means of changes in other features, relaxation and fatigue changes during exploitation). They can not be described by means of dynamic features distinguished by J. Dietrych [18], or presettings by W. Tarnowski [6].

A spring is a design object which is distinguished by the possibility of extensive variation of structures. The **S** = {**E**,**R**} structure is created by **E** elements and **R** relations which describe organization and the manner in which the elements are ordered. In Fig.1. forms of construction of **E** elements in the class of helical and disc springs were systematized.

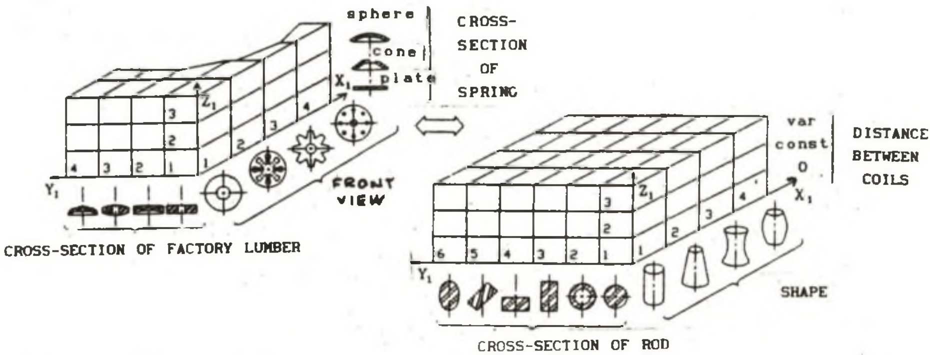

Fig.1. Form of construction of **E** elements (disc and helical spring class)

In Fig.2. is presented the space of **R** relations in an assembly of two linear springs. The attributes are: type of connection for multiplication of deflection or loading and the possibility of the element switch "on/off". At the same time the possibilities of multiple structuring and blocking of one of elements have been omitted.

Using morphological technique for the graphic listing of combinations of solution of **S** structures allows to obtain a numerous set of variants then selection is required.

Each of the spring may realized one or several functions from the following set of exemplary ones: elastic fixing of the elements; passing of the force; shock absorption; forming of a dynamic characteristics; accumulation; measuring of the loading; flexible connection; the set of functions requires transformation. The main function **Fg** is distinguished and it results from the C goal of a design task and the **CH** characteristic of changes in the loading and in the deflection is distinguished (Fig.2e,g- a progressive one for shock absorber with constant force for suspension of the vehicle). It can be possible subordinate [1] sets of structures **S** and characteristic **CH** creating catalogue of descriptions of functions of the structures (Fig.2). That makes selection possible.

The varied character of the required features of construction makes one to look at a construction form various points of view through the criteria of evaluation and to the compromise between expectations and the actual possibilities expressed in the selection criterion. A set of spring evaluation criteria comprises such magnitudes as mass, costs, significant dimensions, volume, energy, reliability, life, functionality, technological requirements, precision of springs. Each of these basic properties of construction may be recorded by means of particular derived criteria.

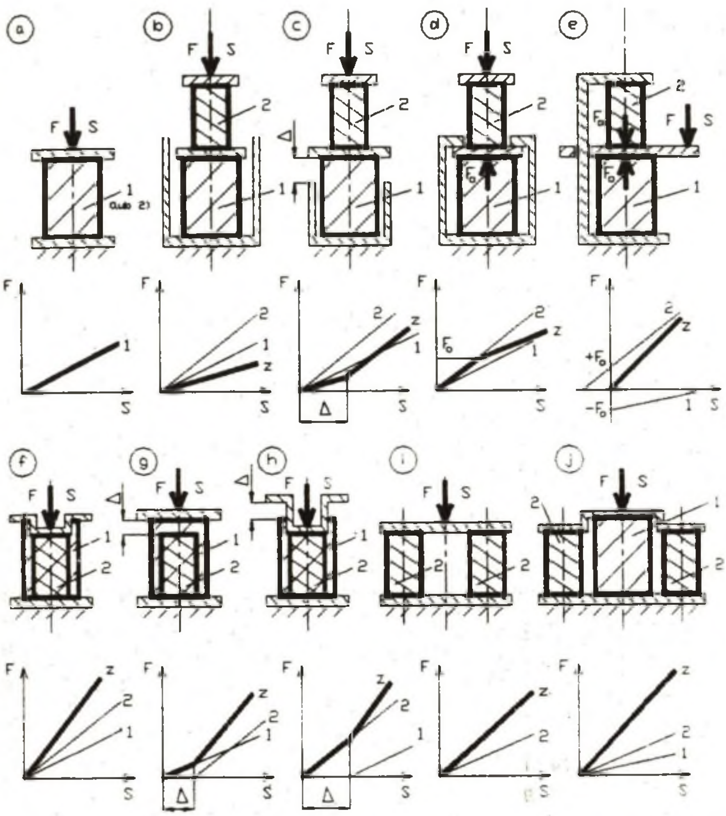

Fig.2. Relation R in an assembly consisting of two different elements and their influence on the curve of characteristics

2. Methods of selection of conceptions of a construction solution

In papers [1,4] the methods of evaluation and selection of conceptions of solutions when searching the proper kind of a single spring from a set of various rod and surface springs were considered in more detail, as well as those when selecting a complex elastic mechanism from a given set of iconic models of such constructions.

In first case a simplified mathematical model of a construction is developed (after Herber and Niepage [5,7]) which is composed of an equality rigidity and strength constraints and the optimization criterion. The requirements of a design task make it possible to select an aggregated task criterion. This is a relation of the Vm spring volume (or the V material volume) or of the m mass of a spring to its rigidity or the accumulated energy Ls. To give an example 11 type of springs were compared in Fig.3 as for the relation of m/Ls mass to the accumulated energy [5].

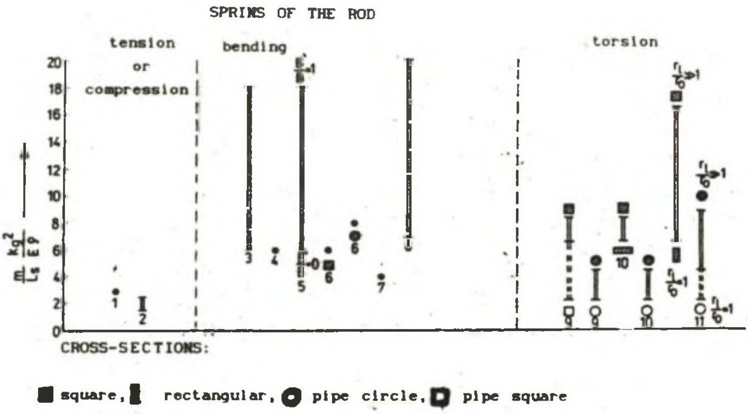

Fig.3. Comparison of springs for the m/Ls criterion according to R. Herber [5] (Notation for types of springs: 1 - rod; 2 - ring; 3 - flat rectangular; 4 - flat triangular; 5 - flat trapezoid; 6 - spiral; 7 - helical torsional; 8 - disc; 9 - torque rods; 10 - helical cylindrical tension; 11 - helical conical telescopic)

In the second case [1] geometric models (sketches of sets of constructions) do not make possible to develop even a simplified mathematical model. In this situation the main criterion could only be determined in a non-formal way (e.g. to ensure the certainty of exploitation of a mechanism over long period with the comfort of using and insignificant costs). Starting with this main criterion we formulated a set of partial criterion on the classification structure of the branch interrelated division. The evaluation was performed on the basis of correlated a multilevel goal and intuitively assumed weight coefficients and values of criteria. In Fig. 4. the structure of the criteria and their weights are given.

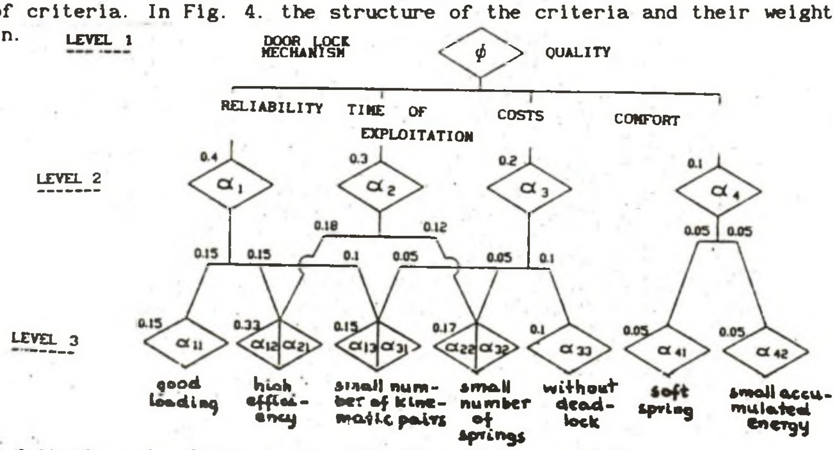

Fig. 4. Criteria and weights during selection of the mechanism

3. Issues in one and multicriteria detailed design

In the class of tasks in the field of parametric optimization an infinite set of variants occurs. A mathematical model is given in full and contains all the constraints. Methods of parametric optimization were applied to solve the following problems: (1) selection of a variant of a parallel connected spring assembly and selection of the optimum construction features of component elements of the helical compression springs with the hierarchical selection of technical and economical criteria; (2) searching of the optimum construction feature helical compression springs with one or many optimization criteria; (3) searching of the optimum construction features of parallel and serially connected disc spring assembly; (4) searching of the optimum construction features of the slotted conical disc spring with the constant force.

3.1. Selection based on the hierarchic optimization of helical springs assemblies

The goal of the task is the selection of on optimum from the point of view of two criteria: a technical (maximum ratio of the work to the volume of the spring mounted) and economic (minimum material cost). Three basic variants of an assembly have been analyzed (Fig.5): a single spring as a background for considerations or an assembly of 2 or 3 concentric parallel connected springs. When two ways of winding, two kinds of the character of loading, two types of endings and 5 manners of fixing the spring ends are taken into account, the theoretical number of variants is 120.

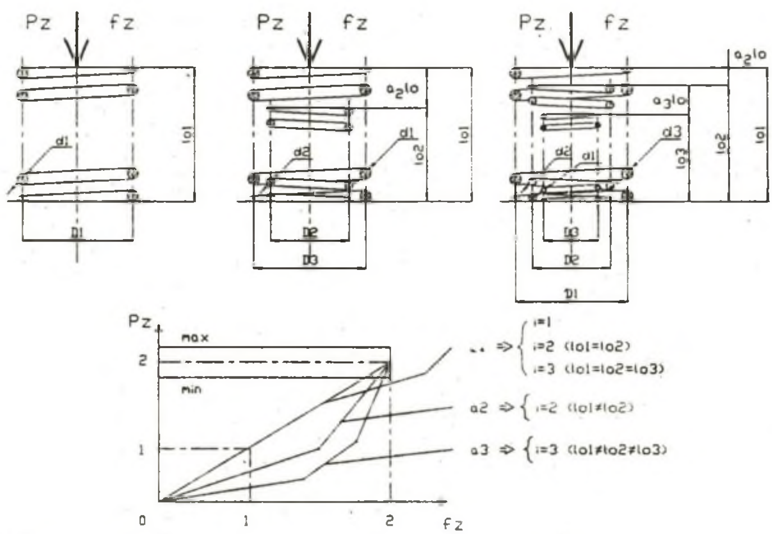

Fig.5. Construction variant and the possible changes in the Pz loading of an assembly in relation to the deflection fz

The task was solved in two stages. In stage 1 optimization [8] of each of the three basis variants has been conducted with respect to technical criteria: $F_{ct} = A / V \Longrightarrow MAX$; and then, in stage 2, the optimum solutions were compared from the point of task criteria of optimization for the multiplication of the technical value Fct and the economic one Fce of the variant:

$Fc = Fct * Fce \Longrightarrow MAX$, where $Fce = Km = Kmi$ (the symbols: A - elastic work; V - volume of the mounted spring; Km - cost of the material of the spring).

In the task formulated in such a way each of the variant constitutes a separate optimization problem of mixed character as for the nature of decision variables. As it is the searches of optimum solution occur in the 3, 6 or 9 dimensional space of decision variables, depending on the number of springs in an assembly (discrete variable: wire diameter di; continuous variable: springs ratios wi=Di/di and the lengths in free state loi).

The following constraints have been adopted in the mathematical model: technological, functional, stiffness, strength, buckling, geometric [13]. The data for the exemplary calculation were as follows: P_{2zmin}= 621N; P_{2max}=759N; f_{2z}=25,2mm; G=79500N/mm^2; E=200000N/mm^2; c_c=0,5; γ=0,6; δ=0,88; ξ=1,15; material: drawn improved wire for valves VD accorgding to DIN 17223 T.2; $\alpha_1=\alpha_2$=1673,42; $\beta_1=\beta_2$=0,128599, d_x=7,5mm; m_k=0,5; s=1,1, a= 0,2351; n=0,4126. Results of calculations are in Tab.1.

From the final list of the normalized values of the task technical-economic criterion Fc of the optimization results a decision was made on the selection of a optimum variant as two spring assembly. A single spring is better than 3 spring assembly. A conclusion can be drawn for this about the purposelessness of using assemblies with more than 2 springs. From the point of view of only the technical criteria a rule is observed that with the increase of the number of elements, the volume of an assembly decreases. In this case the recomendation was found in the literature of the subject [4] concerning the selection of the constant value of the ratio wi=Di/di=cons for all the springs in a assembly. This results from the mixed nature of decision variables and extension of the mathematical model of the construction.

Tab.1. Results of stages 1 i 2 of optimization
(with the normalized values of criteria for each solution variant)

VARIANT	d_{min}	w_i	l_{oi}	z_{ci}	P_{21}	F_{ct}
ONE SPRING	5,5	6,26	91,56	7,39	758,99	0,115
TWO SPRINGS	4,5 3,6	6,99 5,43	83,39 75,46	10,04 13,07	409,99 348,60	0,140
THREE SPRINGS	3,6 2,5 1,6	6,37 5,30 4,35	80,55 74,57 71,05	10,23 16,36 27,55	340,72 215,67 110,01	0,240

VARIANT	k_{ji}	l_{di}	K_{mi}	K_m	F_{ce}	F_{ct}	F_c
ONE SPRING	0,475	1020	0,484	0,484	1,00	0,497	0,479
TWO SPRINGS	0,437 0,399	1193 929	0,521 0,371	0,892 "	0,543 "	0,583 "	0,317 "
THREE SPRINGS	0,399 0,343 0,285	885 744 650	0,353 0,255 0,185	0,793 " "	0,793 " "	1,00 " "	0,610 " "

3.2. Optimization of grouped disc spring

The goal of searches is the selection of the optimum construction feature of the structure and element of a disc grouped spring [8].

The springs structure is formed by serial "i" connection of subassemblies each of which is build from the "n" parallel connected identical elements - disc "e" springs (Fig.6). The main function of spring is shock absorption of the energy of an impact. The springs discussed here have a great energetic capacity due to the non-linear digressive characteristics.

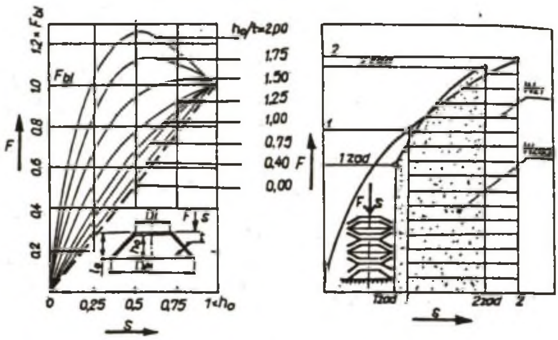

Fig.6. Characteristics force-deflection of an element (a) and an assembly (b)

The rest of requirements for a task formulated in such a way is as follows. The construction should take over the mechanical energy with if exchangeability onto work W21 with the limited value of maximum force F2ii, way of working deflection Sz12-Sz11 and the initial assembly force Fz11. Co-work of a spring with the environment diminishes the extreme dimensions of the external diameter De. It is assumed that ratios among dimensions in an element (example: the ratio of the diameter De/Di; the ratio of the diameter to the thickness of an iron plate De/t) and admissible deformation (for example the ratio of the maximum working deflection to the blocking deflection Sz/ho) corresponds to the ranges of construction and technological requirements of standard disc springs. The strength requirements for the conical surface with quasistatic characteristic of external loading and the requirements concerning the standard of an array of thickness t of discs. In the mathematical model the construction of an assembly may be expressed by means of 8 decision variables and a number of given parameters. Three variables were assumed as discrete ones (thickness of disc "t"; number of springs in cluster "n" number "i" of serial connected clusters) and 5 continuous variables (outside diameter De; the ratio between diameters δ=De/Di; the ratio of deflection to thickness ho/t; the ratio of initial deflection to the blocking one Si/ho and of the maximum deflection to the blocking one s2/ho). Constructions are searched with respect to three criteria separately taken into consideration: extreme volume V $\longrightarrow$ min; elastic work Wz = Wz2 - Wz1 $\longrightarrow$ max; the ratio of the work and the volume Wz/V $\longrightarrow$ max. In this model the same set of 18 constraints occurs for all the 3 criteria: $D_e \le D_{ezad}$, (D_{emax}=120mm); $D_e \ge D_{emin}$, (D_{emin}=1mm); $s_2/h_o \le 0.75$; $s_2/h_o \ge 0$; $h_o/t \ge 0$; $h_o/t \le 2\sqrt{2}$; $\delta \ge 1.3$; $\delta \le 4.0$; $0 \le s_1/h_o \ge 0$; $F_{z11} \ge F_{zadz1}$, (F_{zadz1}=0.0 N); $F_{z12} \le F_{zadz2}$, (F_{zadz2}=142639.2 N); $(s_{z12}-s_{z11}) \le s_{zad}$, ($s_{zad}$=6.6mm); $s_{z12} \ge s_{z11}$; $D_e/t \ge 12$; $D_e/t \le 80$; $|\sigma| \le \sigma_{dop}$, ($\sigma_{dop}$=2500.0 N/mm^2); $W_z \ge W_{zad}$, (W_{zad}=475464.0 Nmm).

Symbols:

De, Di - outside and inside diameter of a spring; F, F2 - coaxial loading of an element and of an assembly; homax - a deflection blocking an element; i - number of clusters; n - number of elements in cluster; N - the assumed friction coefficient for an assembly; Lo - length of unloaded assembly; σ, σdop - working

and permissible stress; t - thickness of a disc; W, Wz - work under deflection of an elastic element and an assembly; s, sz - deflection of an element and an assembly; μ- Poisson number.
Indexes: 1,2 - points of the smallest and the greatest working deflection of characteristics; II, III - places of local maxima of stresses in the cross-section of an element.

The optimizing task discussed here is non-linear due to the character of objective functions and constraints. For the solution a universal package of programs was used in order to aid design in multimodal optimizing problems. A characteristic feature of algorithms and programs is the combination of methods of global searches with local searches. In the initial stage random algorithms CRS and Törn are used. The results of calculation are permanently presented to the decision maker and may be automatically transferred to the programs based on Hook-Jeeves, Nelder-Mead and complex deterministic algorithms [8]. The general structure and functions of the software are shown in Fig.7.

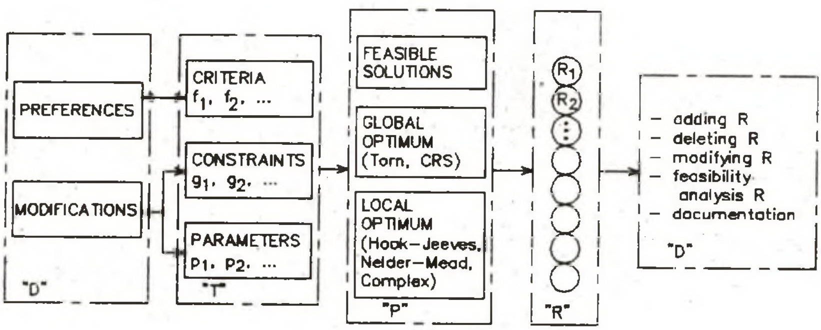

Fig.7. Software structure and functions [8,9]
("D" decisionmaker operations; "T" recording of a design task;
"P" set of the search programs; "R" set of solutions)

What is interesting is the scope of information aiding designers decision on the present searches, the following information is made available, among other: simplex points (values of decision variables, values of penalty function for these points), the current state of active constraints, the history and the present state of the course of calculation (changes of objective function, calculation time). In Tab.2 exemplary results for criteria of the ratio of work and volume of an assembly spring were given. In this case of description of construction by means of 8 decision variables of the solution one could only compare to a limited range with previous result of optimization of a single disc spring with 2 variables [10]. As the optimum one was considered the construction determined by means of Nelder-Mead algorithm. The results did not violate the constraints and were in line with the results of [10].

The experiments prove the need of using the sequential search strategy: form random searches of initial points in the surrounding of the global extreme to the determined searches, particularly complex, with a high precision of results. This cuts the search time short and reduces difficulties with determination of initial point for this type of construction with many variables. Comparison of an optimum construction with the existing one allow to evaluate the efficiency of searches. When combining the construction of a assembly for the industrial disc spring and the standard ones the best result which satisfied all the constraints is worse by 29.3 % when compared with that of an optimum spring as far as the volume criteria is concerned.

Tab. 2. Optimization results

Criterion $\Delta W/V \longrightarrow MAX$

Number of trials	0	700	3000	4000	7500
$\left\lvert \frac{K_{max}-K_{min}}{K_{min}} \right\rvert$ [%]	91.70	39.72	11.64	3.31	0.82
Success [%]	-	55,6	38.8	44.6	44.0
Criterion value 0,1 W/V [N/mm]	8.97	9.27	11.25	11.48	11.94

Construction	De	δ	h_o/t	s_1/h_o	s_2/h_o	t	i	n
Start	57.2	2.26	0.39	0	0.74	3.5	18	3
Optimum	46.1	1.62	0.30	0	0.64	3.5	12	6

Number of solutions in configuration: 175

Time of calculation: 33'

In this class of optimizing task a clutch disc spring with strippings was discussed. The following criteria were adopted: maximum deflection with a quasistatic load and/or minimum punched surface [17]. The search space is described here by 8 decision variables , three of which are discrete ones. The optimum construction when compared with the one we know from literature [16] is better by 30% with respect to deflection and better with the punched surface by 5%.

REFERENCES

[1] Branowski B.: Synthesis methods and design research methods of spring construction, Technical University of Poznań (Poland), 1990 (Rozprawy nr237).

[2] Branowski B., Józefowicz W.: On global optimum search in CAD of springs, Proc. Inter. AMSE Conf. Istanbul 1988 (AMSE Press, Vol.1B).

[3] Branowski B., Józefowicz W.: Heuristic strategy in some combinatorial problems of springs design, Proc. Inter. AMSE Conf. Istanbul 1988 (AMSE Press, Vol.1B).

[4] Branowski B.: Metalowe elementy sprezyste, PWN, Warszawa 1988.

[5] Herber R.: Optimale Metallfedern, Maschinenbautechnik 1968,17,6.

[6] Tarnowski W.: Model procesu wyboru w projektowaniu technicznym, Zeszyty Naukowe Politechniki Śląskiej, z. 72, Gliwce 1984.

[7] Niepage P.: Berechnung von Federn aus Stahl, Vortrag, gehalten in der Technischen Akademie e.V. Wuppertal am 10.3.1968.

[8] Józefowicz W., Dukarski W., Kustoń P.: Zespolone losowe i zdeterminowane programy optymalizacji globalnej i lokalnej, Zeszyty Naukowe Politechniki Poznańskiej, Maszyny Robocze i Pojazdy, Nr33, 1989.

[9] Branowski B., Józefowicz W. i inni: Poszukiwania optymalnej konstrukcji zespolonej sprężyny talerzowej, Zeszyty Naukowe Politechniki Poznańskiej, Maszyny Robocze i Pojazdy, Nr33, 1989.
[10] Niepage P., Muhr K.- H.: Nutzwerte der Tellerfeder im Vergleich mit der Nutzwerten anderer Federarten, Konstruktion, 19 (1967),4.
[11] Rohatyński R.: Operacyjno-systemowe ujęcie procesu projektowania, Biblioteka Informatyki Szkół Wyższych, Wyd. Politechniki Wrocławskiej, Cz.5, (pod red. M. Bazewicza), Wrocław 1990.
[12] Pahl G., Beitz W.: Konstruktionslehre, Springer Verlag, Berlin/Heidelberg, 1977.
[13] Branowski B.:Wahl der optimalen Konstruktionsparameter von Schraubenfedern unter Berücksichtigung der minimalen Kosten oder Baumassen, DRAHT, 31(1980)2, 32(1981)6, 33(1982)2.
[14] Branowski B., Józefowicz W., Werbiński W.: Komputerowe wspomaganie podstawowych obliczeń konstrukcyjnych sprężyn śrubowych i talerzowych, Scientific Papers of the Instytute of Machine Construction and Exploitation of the Technical University of Wrocław, Conferences No.16, 1988: Microcomputer application in strength analysis and structure design, Vol.1.
[15] MUBEA-Tellerfedern Handbuch, Muhr und Bender, Attendorn 1987.
[16] Niepage P., Schiffner K., Gräb B.: Theoretische und experimentelle Untersuchungen an geschlitzten Tellerfedern, Fortschritt-Berichte VDI, Reihe 1, NR.154, Düsseldorf 1987.
[17] Józefowicz W.: Metodologia wspomagania decyzji w systemie CAD, Raport Instytutu Techniki Cieplnej i Silników Spalinowych Politechniki Poznańskiej z prac w Resortowym Problemie RP.I.06, 1990.
[18] Dietrych J.: System i konstrukcja, WNT, Warszawa 1978.

DIE PROBE DER KOMPLEXEN ENTSCHEIDUNGSUNTERSTÜTZUNG IM FEDERENTWURF

Zusammenfassung

In der Arbeit sind Lösungsstrategien der Auswahlaufgabe in verschiedenen Entwicklungsphasen vom Federentwurf dargestellt worden. Im Konzeptionsentwurf basiert die Auswahlstrategie auf den Methoden der Bewertung und der Auswahl. In der Gestaltungsphase sind die einzelnen und multikriterialen Aufgaben auf den Beispielen der parametrischer Optimalisation dargestellt: (1) einzelne Schraubenfedern, (2) Sätze von Tellerfedern, (3) Sätze von Schraubenfedern mit oder ohne Hierarchie der technischen und ökonomischen Kriterien.

PRÓBA KOMPLEKSOWEGO WSPOMAGANIA DECYZJI W PROJEKTOWANIU SPRĘŻYN

Streszczenie

W pracy przedstawiono strategie rozwiązywania zadania wyboru w różnych fazach projektowania sprężyn wspomaganego komputerowo. W projektowaniu koncepcyjnym wybór wariantu rozwiązania konstrukcyjnego oparto na strategii oceny i wyboru. Zagadnienia jedno- i wielokryterialne projektowania szczegółowego pokazano na przykładach optymalizacji parametrycznej sprężyn: (1) pojedynczych śrubowych; (2) układów sprężyn talerzowych lub (3) śrubowych bez lub z hierarchią kryteriów technicznych i ekonomicznych.

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