ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 1992
Seria: MECHANIKA z. 108 Nr kol. 1161

International Conference on
COMPUTER INTEGRATED MANUFACTURING
Internationale Konferenz über
RECHNERINTEGRIERTE FERTIGUNGSSYSTEME
Zakopane, March 24-27 1992

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DESIGN OF GROUPED DISC SPRINGS IN EXPERT AND OPTIMIZING SYSTEM

Summary. In the paper an idea of cooperation of an expert system and an optimization system in solving engineering problems is suggested. The set design task taken from the field of single and grouped disc springs design has been described. The selected set of rules for the expert system used in these springs design is expressed. The heuristic and complete search algorithms for solving these specific tasks are suggested. Results of finding the best solutions of three exemplary design tasks are discussed in the paper

1. Introduction

It occurs in designing that the designer has to reach for catalogues in order to match the unified and ready-made elements or subassemblies for the construction being created [2]. In this work we focus our attention on such a fragment of the design process where a catalogue is used. This catalogue is taken from the producer of disc springs or is created by a computer system.

In the case we discuss there is a design of the construction of grouped disc springs [1]. In engineering practice it is a small, highly specialized part of the process of machinery design. An attempt was made in this work to develop a set of algorithms for solving a task in single and grouped disc springs design. The set of algorithms is the main part of an expert system for these types of tasks. The idea is that the catalogue of these springs is supplied together with a diskette with an expert system which allows to solve a specialized engineering task.

The expert system cooperates with a specialized optimization system for engineering applications. The optimization system is used to solve tasks of designing single disc spring during generating of catalogues of disc springs. The optimization system is used in a parallel with the expert system, in searching of the grouped disc spring.

2. Description of design tasks and methods of solving

The following criteria have been distinguished in this work:
1) difference of the areas between the curve for the expected characteristic and the curve for a characteristic for the obtained object related to the value of the area under the curve of a characteristic expected in the selected range;
2) number of single disc springs in grouped springs. The selection of criterion is a duty of an engineer-user of the system. Below are presented some selected algorithms developed for solving various cases of a design task. For the set of these tasks see Tab. 1.

Table 1. Set of design tasks and alternative ways of finding solution A, A1, A2, A3 (Description: S - single disc spring; G - grouped disc spring; PC - a catalogue from the producer; GC - a catalogue created in a computer system)

		Types of design task due to main characteristic			
Type of design task due to construction		Fig. 1a	Fig. 1b	Fig. 1c	Fig. 1d
1. S, PC	A	search through existing catalogues			
2. G, PC	A1	complete combinatorial search			
	A2	optimization system(discrete problem)			
	A3	heuristic H1	heuristic H2	heuristic H3	heuristic H4
3. S, GC	A1	heuristic H5	heuristic H6	heuristic H7	heuristic H8
	A2	optimization system (continuous-discrete problem)			
	A3	generating & searching of the spring proper			
4. G, GC	A1	generating of the catalogue & complete combinatorial search			
	A2	generating of the catalogue & optimization system (discrete problem)			
	A3	heuristic H9	heuristic H10	heuristic H11	heuristic H12
	A4	generating of the catalogue & heuristic H1	heuristic H2	heuristic H3	heuristic H4

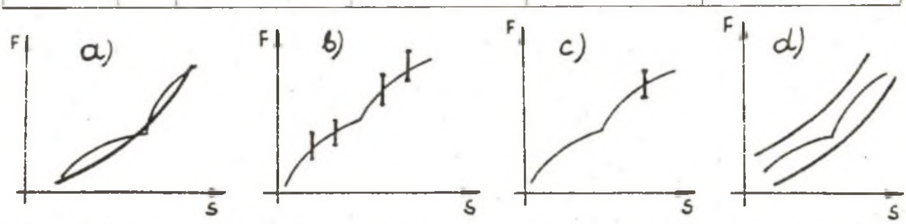

Fig. 1. The main goal of the task: a) matching of two characteristics; b) matching of one characteristic with selected points; c) matching of the range deflections and forces; d) matching of characteristics to the band within which it should be

Kind of design task due to object searched:
I) Single spring (from the catalogue) - see row 1, Tab. 1.
II) Grouped disc spring consisting of the elements taken from the catalogue - see row 2, Tab. 1.
III) Single spring taken from the set (catalogue) created within the computer

system - see row 3, Tab. 1.
IV) Grouped disc spring consisting of the element taken from the set (catalogue) created within the computer system - see row 4, Tab. 1.

The algorithm used in solving problems from first row is obvious i.e., simple search through the catalogue.

The alternative algorithms in row 2 (A1, A2, A3) are of the different nature. There is a certainty of finding the best solution in a limited solution space using algorithm A1 but it requires a lot of computation time. Less time is required by the application an an optimization system but there is no certainty that the best solution will be found since in this case a discrete problem is solved. The advantage an optimization system is its possibility of searching out of the limitations necessary for the complete search algorithm. The fastest way of finding a solution is the heuristic algorithm - A3 application. In this case we can obtain a reasonable solution but not an optimum one. In cases of heuristic algorithms there are no limitations in solution space.

A set of tasks from row 3 concerns such situations when it is impossible to use the existing catalogues and one needs a single disc spring. A typical solution of such a problem is using either a heuristic algorithm or an optimization system. The new idea suggested in this paper is to solve such a problem in two steps: (1) generation of a catalogue within the computer system; (2) searching of the solution through this catalogue.

In row 4 we deal with the tasks similar to those in row 2 thus we use the same algorithms A1, A2, A4 like in case of row 2, with one exception, since the catalogue is generated before the algorithms are used. New alternatives (A3) of solving these tasks are heuristic algorithms H9 - H12.

The main goal of the work undertaken is to create the CAD system for solving the set of design tasks expressed in Tab. 1. This system will consist of the expert system integrated with the optimization system.

3. Selected rules and algorithms

In the system the knowledge is used which concerns:
- a task upon specifications given by the user;
- principles of determining solution space;
- rules for estimation of the calculation time;
- rules of matching algorithms and tasks;
- rules of using algorithms;
- elementary rules.

Using this knowledge one can determine the solution space and select algorithms for the design task. The calculation scenario with many variants is suggested to the user for him to accept. The selected rules and concepts applied in defining the scenario are presented below. Due to the shortage of space the rules have been recorded briefly and selectively. The concepts which describe the construction of the spring:
- cluster - is a set of springs of the same type put one into another (usually from 1 to 3 single springs);
- subassembly is a set of identical clusters;
- grouped disc spring is a set of subassemblies;

The symbols used: lwm - number of variants for grouped spring built from single disc springs of one type; lwv - number of variants for grouped springs built from various single disc springs; tjw - calculation time of one variant; tm - the estimated time of calculation of all variants for grouped disc springs built from single disc springs of one type; tv - the estimated time of calculation of all variants for grouped disc springs built from various single disc springs; td - the maximum time given by the user for solving the design task; smax - the maximum admissible number of serial connections in a grouped spring; rmax - the maximum admissible number of parallel connections in a grouped spring; typm - the task of constructing a grouped spring from a single spring of one type; typv - the task of constructing a grouped spring from a single spring of various types;

In order to make a decision on the use of one of the algorithms one should first calculate tjv on the basis of an exemplary calculation and then tm and tv expressed by formulas: $tm=lwm*tjw$, $tv=lwv*tjw$
where values lwm and lwv are calculated according to the formulas given in sectio

Exemplary rules:
R1. If $tm + tv < td$ then execute programs of heuristic and complete search;
R2. If $tm < td$ then execute complete search program;
R3. If $tm > td$ then execute heuristic search program;
R4. When number of parallel connections in a given cluster = 2 then smax=15;
R5. When number of parallel connections in a given cluster = 1 then smax=20;
R6. The reduction of the catalogue as the result of rejecting of all springs with a maximum force smaller than the value calculated as the dividing of maximum deflection for a given task by the maximum number of parallel springs
R7. The reduction of a catalogue as the result of rejecting of the springs which do not meet the condition on internal and external diameters;
R8. The reduction of the catalogue due to the construction conditions as regards frictions (rmax= 2 to 5);

4. Determination of numeracy of solution space

The determination of the actual numeracy of a solution space is very important in the system since it is a basis for decision making whether the algorithm of the complete search can be used. This algorithm guarantees finding the optimum in the solution space under discussion. Below is quoted one way of calculating the maximum number of variants for grouped disc springs based on one type of single spring taken from the catalogue.

The general formula for calculation of the maximum number of variants of a grouped spring under given assumptions is as follows:

$$lw = k * \sum_{z=1}^{zp} \binom{rmax}{z} * smax^{z} \qquad (4.1)$$

where

zp - maximum number of subassemblies;
rmax- maximum number of parallel connections of springs;
smax - maximum number of serial connections of springs;
k - number of springs in a catalogue.

All the above parameters express the limitations of a solution space.

5. The set of exemplary design tasks

The set of exemplary tasks concerns the design of grouped disc springs. Research and engineering work has long been now under way concerning these more and more popular types of springs.

Three exemplary design tasks were solved to make comparisons among optimization system applications, heuristic and complete search algorithms. All these tasks belong to the group mentioned in the second row and the first column of Tab. 1. In every task two criteria are taken into account: (1) difference of the areas between the curve for an expected characteristic and the curve for a characteristic for the obtained object related to the value of the area under the curve of a characteristic expected in the selected range; (2) the number of single disc springs in a grouped spring. In the optimization system a multiplication of these criteria plays the role of the objective function. In the following formulas F - expresses the force [N] and s - describes the deflection [mm] under the force F.

Task 1: The aim of this task is to find the grouped disc spring with the expected characteristic:

$$s=0.022364 \cdot (\ln F - 5.29832) \ [mm] \qquad \text{(Task 1)}$$

$s \in (2.46, 60.6)$ [mm] $\quad F \in (600, 3000)$ [N]

According to formula (4.1) the maximum numeracy of solution space can be expressed as:

$$lw = 279 * \sum_{z=1}^{4} \binom{4}{z} * 6^{z} = 669\ 600$$

The solution space was decreased for the complete search algorithm - see sec. 8.

Tasks 2 and 3: The aim of these tasks is to find the grouped disc spring w expected characteristic:

$$F=3700 \cdot s^{1.176} \ [N] \qquad \text{(Task 2)}$$

$s \in (12, 122)$ [mm] $\quad F \in (69000, 1050000)$ [N]

$$s = e^{(F/0.0022364)} - 1 \ [mm] \qquad \text{(Task 3)}$$

$s \in (2.46, 60.6)$ [mm] $\quad F \in (600, 3000)$ [N]

6. Complete search algorithm

In order to determine all the possible variants of the construction of a grouped spring for a given task one should quote the maximum number of zp subassemblies of which a spring can be built. The maximum number of rmax parallel connections for each subassembly and the maximum number of smax serial connections for each subassembly are determined. This is necessary as without these limitations the solution space is infinite and it is impossible to apply the algorithm of the complete search. The algorithm is expressed in Pascal as a procedure "variants".

The following structure of data was adopted to represent a variant.

```
type  subassembly = record  r,s : integer; end;
       arraytyp    = array [1..zp] of subassembly;
var    variant     : arraytyp;
```

This is an array with as many elements as the given variant has subassemblies described by figure zp. One element of the array is the record holding the number of parallel connections r and the serial s ones for the subassembly. An algorithm of complete search is suggested as a recursive one.

The variants are sequentially generated by the recursive solution space search. After the variant has been generated the following operations are being performed on it: testing the constraints, calculations of the objective function, the optional insertion of the variant into the set of "promising" solutions, and than the next variant is being generated in "its place". This procedure generates sets of variants for the number of subassemblies from 1 to "zp". The recursive procedure "parallel" is called once for every "z". This procedure determines the number of parallel connections in each of these "z" subassemblies.

```
procedure variants (rmax,smax,zp:integer);
var z:integer;
begin
if zp>rmax then zp:=rmax;
for z:=1 to zp do  parallel(1,z);
end;
```

In the procedure "variants" another procedure "parallel" is called in recursively. The procedure "parallel" determines the structure of single disc spring connections, but only a parallel connections are in fact established. From now on this will be called "structure of parallel connections". In further processing the sets of variants are generated for every "structure of parallel connections". The variants belonging to one set differ only in so called "structure of serial connections"

```
procedure parallel(z,act_zp:integer);
{z  -actual  number  of  subassembly;
 zp_act -actual admissible number of subassemblies }
var r : integer;
begin
if z=1 then for r:=1 to rmax-act_zp+z do
             begin
             variant[z].r:=r;
             if   act_zp<>1   then parallel(z+1,act_zp)
                                 else serial(1,z);
             end
        else
             if act_zp=z then   for r:=variant[z-1].r+1 to rmax-act_zp+z do
                                  begin variant[z].r:=r; serial(1,z); end
                          else
                            for r:=variant[z-1].r+1 to rmax-act_zp+z do
                              begin variant[z].r:=r; parallel(z+1,act_zp); end
end; { parallel }
```

Generation of various "structures of serial connections" is the task of "parallel" procedure which with the determined "structures of parallel connections" is a full determination of the variant of a grouped disc spring as for its structure of connection. Within the "parallel" procedure the final determination of variant of a grouped spring takes place which consists in combining the given structure with the given disc springs taken sequentially from the catalogue. For every variant, i.e. structure and disc spring the values of objective function are calculated, constraints are tested and so on.

```
procedure serial(z.act_zp:integer);
var s:integer;
begin
if z=act_zp then for s:=1 to smax do
                 begin
                 variant[z].s:=s; number_of_subassemblies:=z;
{The values of objective function are calculated, constraints are tested etc. }
                 end
             else
                 for s:=1 to smax do
                  begin variant[z].s:=s; serial(z+1.act_zp); end;
end; { serial }
```

7 The role of an expert system

An expert system in the process of solution search plays the role of a mediator between application programs and the designer and that of a guide for achieving the necessary solution. Its main tasks are as follows:

- managing of the data flow and control;
- independent selection of parameters for the algorithms or supporting the user in this selection;

- recording of the process of designing and also of the solutions obtained;
- operations on the catalogue such as its redefinition, extension, generation of a new catalogue;
- visual presentation of the obtained solution.

8. Solutions of exemplary design tasks

The structure of the grouped disc spring for every solution was described in the following manner:
[<index of single spring in catalogue>, <s - number of subassemblies from 0 to smax, when r=1>, <s - number of subassemblies from 0 to smax, when r=2>, ... , <s - number of subassemblies from 0 to smax, when r=rmax>]

In this convention s=0 means that this subassembly doesn't exist in the structure described of the grouped disc spring.

Table 2. The set of solutions of exemplary tasks

	ALGORITHM		
	optimization	heuristic	complete search
Task 1			
1. number of disc springs	15	17	24
2. difference of areas	473	398	195
3. multiplication of 1 & 2	7095	6766	4680
4. structure	56,6,3.1	76,5,0,4	65,4,2,0.4
5. time of calculations	1080	3	3633
Task 2			
1. number of disc springs	74	51	41
2. difference of areas	1150246	5135256	1771703
3. multiplication of 1 & 2	85118204	261898056	72639823
4. structure	278,3,2,11,1,6	267,13,19	279,4,14,3
5. time of calculations	1200	3	2400
Task 3			
1. number of disc springs	4	3	3
2. difference of areas	179	286	286
3. multiplication of 1 & 2	716	858	858
4. structure	108,2.1	98.3	98.3
5. time of calculations	480	3	2100

In task 1 the best result was obtained using an algorithm of the complete search but this required long time of searching. The result obtained by means of the heuristic algorithm to a great extent satisfies characteristics as a smaller number of springs was used.

In task 2 the best result was also obtained using the algorithm of the complete search. The output for computation was smaller than in case of task 1 despite greater values of smax, rmax parameters due to a dramatic reduction of the size of the catalogue to only 12 %.

In task 3 the best result was obtained using optimization algorithms. Such a result was obtained because for the algorithms of the complete search the solution space was limited so that the optimum was beyond it. In this connection calculations were performed again according to the algorithm of the complete search and the following result was obtained:
1. 5; 2. 121; 3. 603; 4. [131,1,2]; 5. 70s.

9. Conclusions

Depending on the complexity of a task one can use either a heuristic or a complete search algorithm within the limited solution space. Optimization algorithms may be performed irrespective of the complexity of the task except for cases from row 1, Tab. 1. The application of the complete search can not be taken into consideration in many cases because of a very long time of calculations. In this situation there is only a possibility of using heuristic algorithms and/or optimization algorithms. It should be emphasized that algorithms of the complete search deal mostly with the limited solution space. As can be seen from the numerical experiments a skillful control of the system containing different types of algorithms is necessary. These operations require expert knowledge, experience and an analysis of numerous data. Such operations may be efficiently performed by an expert system.

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PROJEKTIERUNG DER TELLERFEDERSÄTZEN IM EXPERTEN- UND OPTIMIERUNGSSYSTEM

Zusammenfassung

In der vorliegenden Arbeit wurde die Konzeption der Zusammenarbeit zwischen dem Experten- und Optimierungssystem in der Lösung der Ingenieuraufgaben vorgestellt. Es wurden die Aufgaben aus dem Projektierungsbereich der Einzelnen- und Komplexentellerfedern beschrieben. Man gab die ausgewählten Regeln für das Expertensystem. Es wurden die heuristischen Algorithmen sowie Algorithmen der vollständigen Dursicht für die spezifischen kombinatorischen Aufgaben vorgeschlagen. Es wurden auch die besten Ergebnisse für drei Beispiele der Projektierungsaufgaben vorgestellt.

PROJEKTOWANIE ZESPOŁOWYCH SPRĘŻYN TALERZOWYCH W SYSTEMIE DORADCZYM I OPTYMALIZACYJNYM

Strzeszczenie

W pracy podano koncepcję współpracy między systemem ekspertowym a optymalizacyjnym w rozwiązywaniu zadań inżynierskich. Opisuje się zadania z dziedziny projektowania pojedyńczych i zespołowych sprężyn talerzowych. Podano niektóre reguły systemu doradczego. Zaproponowano algorytmy heurystyczne i pełnego przeglądu dla zadań z projektowania zespołowych sprężyn talerzowych. Prezentowane są najlepsze rezultaty dla 3 przykładowych zadań projektowych.

Wpłynęło do redakcji w styczniu 1992 r. Recenzent: Wojciech Cholewa