microCAD-SYSTEM '92

Nemzetközi Számítástechnikai Találkozó

1992. február 25–29.

SZÁMÍTÁSTECHNIKA MŰSZAKI ALKALMAZÁSA ELŐADÁSANYAGAI I.

Irodalom

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OPTIMIZATION TECHNIQUES IN THE ECONOMIC DESIGN OF STEEL STRUCTURES

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SUMMARY

The different single- and multiobjective optimization techniques makes the designer able to determine the optimal sizes of structures, to get the best solution among several alternatives. The efficiencies of these techniques are different. We have shown the efficiency of these techniques at the optimum design of single bay frames, main girders of overhead travelling cranes, spindle-bearing systems of a machine tool, stiffened plates.

ÖSSZEFOGLALÁS

A különbözö egy- és többcélfüggvényes optimáló módszerek lehetövé teszik a tervezö számára, hogy meghatározza különféle szerkezetek optimális méreteit, hogy megkapja a legjobb megoldást a lehetséges alternatívák közül. Az optimáló módszerek hatékonysága különbözö. Megmutatjuk ezen módszerek hatékonyságát különféle szerkezetek optimális méretezésénél: egyhajós csarnokkeret, futódaru hidfötartója, tengely-csapágy rendszer szerszámgépnél, bordázott lemez.

1. INTRODUCTION

Single- and multiobjective optimization techniques are good tools for finding the best results of the design problem. The developed computer code contains seven various type multiobjective and five single-objective optimization techniques [1,15].

The efficiency of the computer code is shown at the design of single-bay plane frame, with I-cross section with continuously increasing web height, taking account 3 objective functions and 35 inequality constraints. The second application is the design of a welded, stiffened box girder as a main girder of an overhead travelling crane with 4 objectives and 16 inequality constraints. The third application is the design of a spindle-bearing system with 3 objectives and 10 inequality constraints. The fourth application is design of cellular plates with 3 objectives and 14 inequality constraints.

In these cases the optimization techniques had different efficiencies, one or two is better to use for that problem than the others, regarding the single-objective optimization techniques. At the multiobjective optimization techniques the main difference is, what kind of Pareto optima can be found and how close is it to the ideal solution. The great number of Pareto optima gives the possibility for the designer to choose the "best" from them [10,11,12]. See Table 1.

2. SINGLE-CRITERION OPTIMIZATION TECHNIQUES

A large number of algorithm have been proposed for the nonlinear programming solution. Each technique has its own advantages and disadvantages, no one algorithm is suitable for all purposes. The choice of a particular algorithm for any situation depends on the problem formulation and the user.

The general formulation of a single-criterion nonlinear programming problem is the following:

$$\text{minimize} \quad f(x), \qquad x = x_1, x_2, \ldots, x_N,$$
$$\text{subject to } g_j(x) \geq 0, \qquad j = 1,2,\ldots,P,$$
$$h_k(x) = 0, \qquad k = P+1,\ldots,P+M. \qquad (1)$$

2.1 THE FLEXIBLE TOLERANCE (FT) METHOD

The FT [2] algorithm improves the value of the objective function by using information provided by feasible points, as well as certain nonfeasible points, termed near-feasible points. The near-feasibility limits are gradually made more restrictive as the search proceeds toward the solution, until in the limit only feasible x vectors are accepted.

With this strategy (1) can be replaced by a simpler problem, having the same solution:

$$\text{minimize} \quad f(x),$$
$$\text{subject to } \Theta^k - T(x) \geq 0 \qquad (2)$$

where Θ^k is the value of the flexible tolerance criterion for feasibility on the kth stage of the search, and $T(x)$ is a positive functional of all the equality and/or inequality constraints of (1), used as a measure of the extent of constraint violation. It is very important to choose a good size of initial polyhedron, which is difficult, when the difference between the values of unknowns is great.

2.2 THE DIRECT-RANDOM SEARCH (DRS) METHOD

The DRS [3] method combined three techniques: the direct search of Hooke and Jeeves, the random search, and the penalty function concept into one computer code. The penalty function is formed as follows:

$$P(x,r) = f(x) + \delta_i \, r_i \, g_i^2(x), \qquad (3)$$

$\delta_i=(1-U_i)$ is zero if the constraints is satisfied and unity otherwise. The initial value of r is as follows:

$r_i^0 = 0.02/\ (P^* g_i(x^0)\ f(x^0))$, where P^* is the number of constraints.

Minimization of the P function is carried out by the Hooke and Jeeves technique for the successive series of increasing value of r_i from stage to stage. The search terminates when all the constraints are satisfied or when the absolute difference between the value of the

constraint at the beginning of the search and at the end is less than some prespecified tolerance.

2.3 THE HILLCLIMB (HI) ALGORITHM

The procedure is based on the "automatic" method proposed by Rosenbrock [4]. The method of rotating coordinates can be considered as a further development of the Hooke and Jeeves method. At the algorithm, the coordinate system is rotated in each stage of minimization. No derivatives are required. The procedure is very quick, but it gives usually local optima, so it is advisable to use more starting points.

2.4 THE COMPLEX PROGRAMMING METHOD (BO)

Using random numbers a so-called "complex" is generated from the upper and lower bounds of variables. Computing the coordinates of the centroid some geometrical replacements are used:

$$x_{ij} = x_i^L + r_{ij}\ (x_i^U - x_i^L) \qquad i=1,\ldots,N, \qquad j=2,\ldots,K. \quad (4)$$

where r_{ij} are the random numbers with a uniform distribution over the interval 0-1.
x_i^U and x_i^L are the upper and lower limits of, variables.

- rejection with the coefficient through the centroid. If $\beta = 1$ that is a simple rejection, if $\beta > 1$ ($\beta = 1.3$) that is an expanded rejection.
- halving the distance between the point and the centroid (Γ=0.5).

The convergence criterion is

$$f_{max} - f_{min} < \mu \qquad (5)$$

when it is fulfilled, the procedure is terminated [5]. The procedure is robust, it gives global optima, but if the number of unknowns (N) and the size of complex (K) are great, it becomes very slow.

2.5 THE DAVIDON-FLETCHER-POWELL METHOD (DFP)

The variable metric method of Davidon was extended by Fletcher and Powell [6]. This method is one of the best general-purpose unconstrained optimization techniques making use of the derivatives that are currently available.
The method computes the gradient of the function $f(x)$ at the initial point and sets

$$S_i = -H_i \nabla f(x_i), \qquad (6)$$

Find the optimal length Ω_i, in the direction S_i,

$$x_{i+1} = x_i + \Omega_i S_i \qquad (7)$$

where H_i is taken as the identity matrix.
Find the new point x_{i+1} for optimality and if x_{i+1} is optimal, terminate the iterative process, otherwise continue calculation.
The interior penalty function method is used in the algorithm to be able to handle constraints. The Φ function is defined as follows:

$$\Phi(x,r_k) = f(x) + r_k \sum_j 1 / g_j(x) \quad (8)$$

can be seen that the value of the function Φ will always be smaller ar f since $g_j(x)$ is negative for all infeasible points x.

The cubic interpolation method is used for finding the minimizing ep length Ω_i, in four stages. Sometimes there is an overflow at nction, because $g_j(x)$ is close to zero near the optimum, so the nvergence criterion is very important.

The program system can be seen an Table 1.

3. MULTICRITERIA OPTIMIZATION TECHNIQUES

A multicriteria optimization problem can be formulated as follows :

$$\text{Find } f(x^*) = \text{opt } f(x), \quad (9)$$

$$\text{such that } g_j(x) \geq 0, \quad j = 1,\ldots,M,$$

$$h_i(x) = 0, \quad i = 1,\ldots,P.$$

ere x is the vector of decision variables defined in N-dimensional clidean space and $f_k(x)$ is a vector function defined in K-nensional Euclidean space. $g_j(x)$ and $h_i(x)$ are inequality and uality constraints.

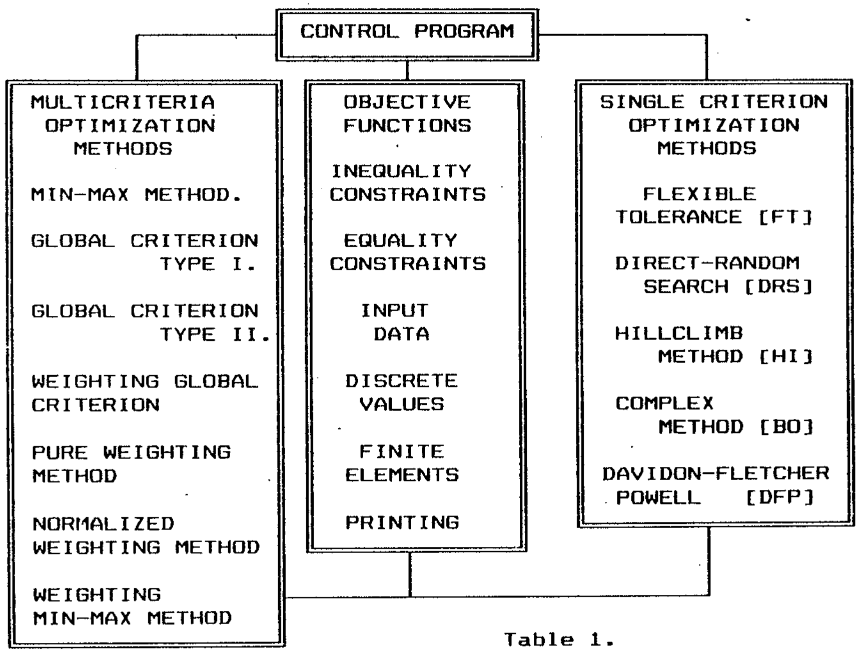

Table 1.

The solutions of this problem are the Pareto optima. The definition of this optimum is based upon the intuitive conviction that the point. x* is chosen as the optimal, if no criterion can be improved without worsening at least one other criterion.

3.1 THE MIN-MAX METHOD

The min-max approach to a linear model was proposed by Jutler [7]. The min-max optimum compares relative deviations from the separately attainable minima. The relative deviation can be calculated from

$$z_i'(x) = \left|(f_i(x)-f_i^{\varnothing})\right| / \left|f_i^{\varnothing}\right| \quad \text{and} \quad z_i''(x) = \left|(f_i(x)-f_i^{\varnothing})\right| / \left|f_i(x)\right|$$

Knowing the extremes of the objective functions which can be obtained by solving the optimization problems for each criterion separately, the desirable solution is the one which gives the smallest values of the increments of all the objective functions. The point x* may be called the best compromise solution considering all the criteria simultaneously and on equal terms of importance.

$$z_i(x) = \max \{ z_i'(x), z_i''(x) \} \qquad i \in I \quad (10)$$

$$\tau(x^*) = \min \max \{ z_i(x) \} \qquad x \in X, \quad i \in I \quad (11)$$

where X is the feasible region.

3.2 THE WEIGHTING MIN-MAX METHOD

Using the min-max approach together with the weighting method, a desired representation of Pareto optimal solutions can be obtained [9]

$$\Pi\, z_i(x) = \max \{ w_i\, z_i'(x),\ w_i\, z_i''(x) \} \qquad i \in I \quad (12)$$

The weighting coefficients w_i reflect exactly the priority of the criteria. We can get a distributed subset of Pareto optimal solutions.

3.3 GLOBAL CRITERION METHOD

A function which describes a global criterion is a measure of "how close the solution from the ideal vector of $f^{\varnothing}$. The most common form of this function is (type I) :

$$f(x) = \sum_i \left(\left(f_i^{\varnothing} - f_i(x) \right) / f_i^{\varnothing} \right)^P \quad (13)$$

Salukvadze [8] has suggested P=2, but other values of P can be used. Naturally the solution obtained will differ greatly according to the value of P chosen.

It is recommended to use relative deviations (type II) :

$$L_p(f) = \left[\sum_i \left| f_i^{\varnothing} - f_i(x) \right|^P \right]^{1/P} \qquad 1 \leq P \leq \infty \quad (14)$$

3.4 WEIGHTING GLOBAL CRITERION METHOD

Using weighting parameters we could get a great number of Pareto optima with (13). If we choose P=2, which means the Euclidean distance between Pareto optimum and ideal solution [1]. The coordinates of this distance are weighted by the parameters as follows:

$$L_p(f) = \left[\sum_i \left| w_i\, f_i^{\varnothing} - f_i(x) \right|^P \right]^{1/P} \qquad 1 \leq P \leq \infty \quad (15)$$

3.5 PURE WEIGHTING METHOD

The basis of this method consists in adding all the objective functions together using different weighting coefficients for each. It means, that we transform our multicriteria optimization problem to a scalar one by creating one function of the form:

$$f(x) = \sum_i w_i f_i(x) \quad \text{where} \quad w_i \geq 0 \quad \text{and} \quad \sum_i w_i = 1 \qquad (16)$$

The result of solving this model can vary significantly as the weighting coefficients change, and the nominal value of the different objective functions.

3.7 NORMALIZED WEIGHTING METHOD

In the pure weighting method, the weighting coefficients do not reflect proportionally the relative importance of the objective. At the normalized weighting method w_i reflect closely the importance of objectives, all functions are expressed in units.

$$f(x) = \sum_i w_i f_i(x) / f_i^{\circ} \qquad (17)$$

The condition $f_i^{\circ} = 0$ is assumed.

4. APPLICATIONS

4.1 OPTIMUM DESIGN OF PLANE FRAMES USING FEM

Objective functions:
- mass of the frame,
- cost of the frame containing material, welded and surface preparation costs,
- mass/floor space ratio to be minimized.

Unknowns: height of webs at columns and rafters at pin, apex and eaves points, thickness of webs at columns and rafters, width and thickness of flanges both at columns and rafters. The 10th variable is the span length of the single bay frame.

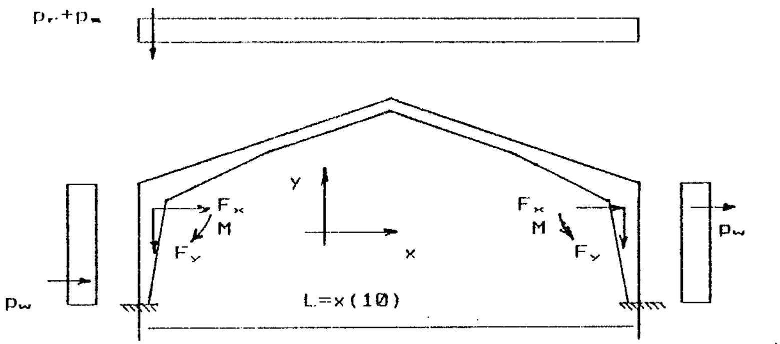

Fig. 1. The single bay welded plane frame structure

Constraints: static stress constraints at different stress-maximum points at columns and rafters, local web and flange buckling, lateral buckling for the compressed flange, elastic lateral buckling at the eaves points both in columns and rafters. Vertical and horizontal displacement of the frame, size constraints.

The frame can be a gantry one, with a crane runway on it. In this case the Hillclimb method was the most efficient, it could find more quickly the optima, using FEM subprograms for stress and displacement calculations at different topology. It is possible to use higher strength steel.

4.2 OPTIMUM DESIGN OF A MAIN GIRDER OF AN OVERHEAD TRAVELLING CRANES

Objective functions:
- mass of the main girder,
- welded cost,
- surface preparation costs,
- total cost to be minimized.

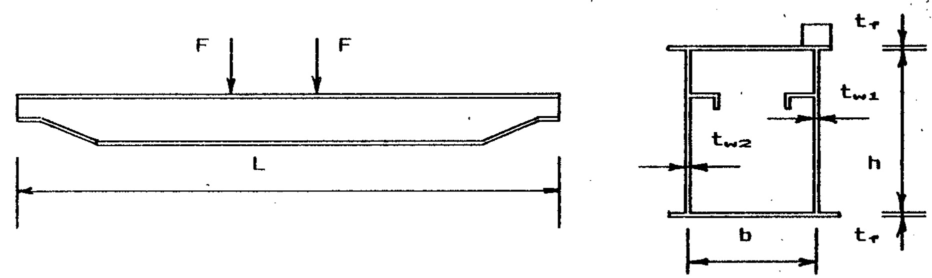

Fig. 2. Cross section of the welded main girder of overhead travelling crane

Unknowns: height and thicknesses of webs, h, t_{w1}, t_{w2}, width b, and thickness of flanges t_f.

Constraints: stresses, web bucklings, flange bucklings due to main loading, stresses, web bucklings, flange buckling due to total loading, fatigue constraints on weldments, deflection of the girder, size constraints. There is a possibility of using higher strength steels [13].

The Complex method could find quickly the global optima of the multiobjective optimization problem in this case.

4.3 OPTIMUM DESIGN OF MACHINE-TOOLS SPINDLE-BEARING SYSTEMS

Objective functions:
- mass of the spindle to be minimized,
- rigidity of the spindle-bearing system to be maximized,
- eigenfrequency of the system to be maximized.

Unknowns: length between the bearings, diameter of the spindle at bearing.

Constraints: radial displacement, radial rigidity, eigenfrequency, size constraints.

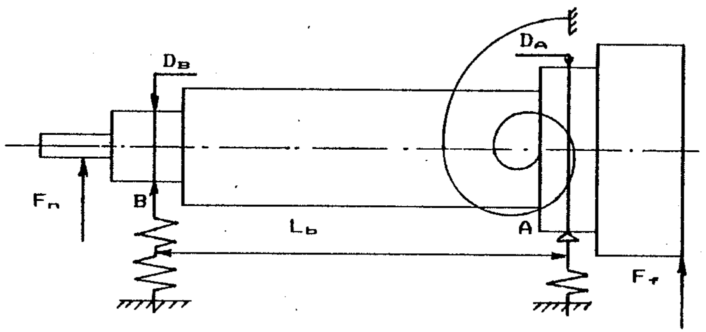

Fig. 3. The spindle-bearing system

The Flexible Tolerance method was very efficient in finding the optimum using the finite strip method, but it needed more computation time [14]. The values of the three objectives at single-objective optimization and using the min-max multiobjective method, where the relative importances are the same, can be seen on Fig. 4.

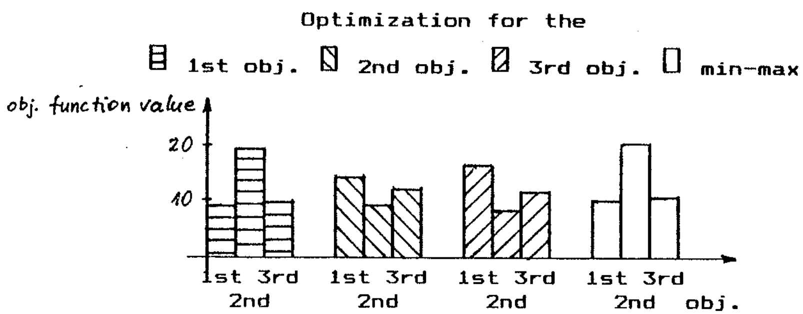

Fig. 4. Solution of the single- and multiobjective optimization

4.4 OPTIMUM DESIGN OF STIFFENED PLATES

Objective functions:
- mass of the plate,
- cost of the plate including material and welding costs,
- deflection of the cellular plate to be minimized.

Unknowns: thicknesses of cover plates and stiffeners, height of stiffeners, number of stiffeners.

Constraints: normal stress constraints at cover plates, shear constraints at stiffeners, deflection constraints, local buckling constraints, size constraints. There is a possibility of using higher strength steels.

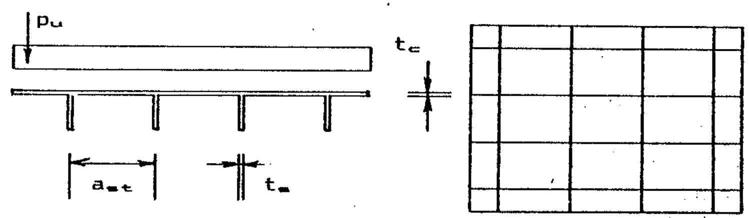

Fig. 5. The stiffened, welded plate structure

The Direct-Random Search technique was very useful in this case. It usually gives global optimum for the structure.

The program system was made in MS FORTRAN 5.0 on PC/AT/386 compatible computer. If we write the programs for example in C language, at that case the Complex method was quicker than the Hillclimb, but in FORTRAN the Hillclimb method was the quickest one, but usually gave local optimum. We have made some of the optimization programs in Quick Basic and the developing time was much smaller, but the runtime was longer. All the single-objective methods can find a feasible starting point, and give an optimum with unbounded and with discrete values. There is a range of discrete values is given for every variables.

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MÉRNÖKI ALKALMAZÁSOK - IMS FÖDÉMTŐL A KAZETTAÁTRAKÓIG

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SUMMARY:

In practical point of view sometimes impossible to use the standard FEM programs in the analysis of the technical problems. The special behaviour of the structures, the complex geometry, the interconnected soil and stucture or the special character of the loads require individual solutions. This paper presents some examples which were solved by the authors in the years past such as: analysis of the load-bearing capacity of the IMS floors in consequence of the cable-corrosion, displacement analysis of a sluice-gate and the ring-shaped foundation of a cooling tower, dynamic analysis of a fuel handling hoist etc.

ÖSSZEFOGLALÁS:

A standard véges elem programok alkalmazása a műszaki feladatok egy részének megoldására néha nem lehetséges. A szerkezet speciális jellege, geometriai elrendezése, esetleg a talaj és szerkezet kapcsolata, vagy a terhek sajátosságai egyedi megoldásokat igényelnek. Az előadás erre mutat be néhány példát, amelyet a szerzők az elmúlt években oldottak meg, úgymint IMS födémek kábel-korrozió miatti teherbíráscsökkenésének vizsgálata, hajózsilip és hűtőtorony alapgyűrű elmozdulás vizsgálata, kazettaátrakó dinamikai vizsgálata stb.

1.IMS födémek kábel korrozió miatti teherbíráscsökkenésének vizsgálata

Az IMS szerkezet előregyártott vasbeton elemekből összeszerelt utófeszített váz.