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Optimal design through the utility function parameterization method on electromechanical actuators

To cite this article: R I Coteiu *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **514** 012017

Optimal design through the utility function parameterization method on electromechanical actuators

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Abstract. This paper presents an analytical and computer aided procedure for the multicriteria design optimization of the electromechanical actuator. The constraints are defined to find the basic constructive parameters which defined have to by simultaneous optimized through objectively severe functions. For the defined to find the multi-criteria optimization model of the electromechanical actuator a computer program based in interactive dialogue in developed in an algorithm. The results of the program are presented considering a multicriteria optimization algorithm of the new electromechanical actuator.

1. Introduction

The electromechanical actuator has a very significant place among the transmissions, which are used in many branches of industry, in the field of machine tools, and robots have an essential importance these of programmed position. The design of roto-translation transmissions requires conditions regarding the efficiency, volume factor of safety, is presented in figure 1 [1].

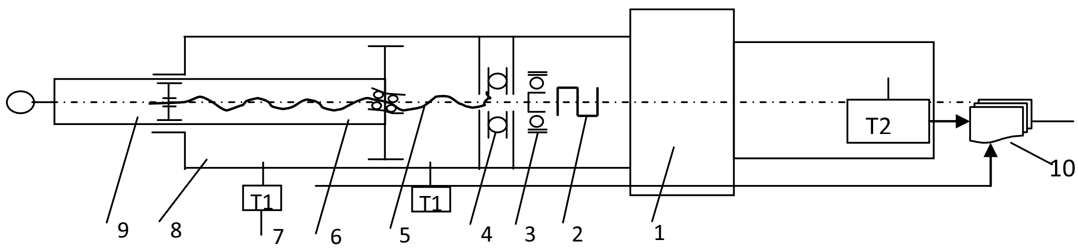

Figure 1. The mechanic system of linear electromechanical actuator: 1- engine, 2-coupling, 3,4-bearing, 5 -screws, 6- nut, 7- transducer, 8-body, 9-rod, 10-controller

The applicative and experimental research has envisaged the practical checking and complementation of theoretical models adopted for efficiency, as well as the convergence with reality of the procedures of approaching the problems observed. The creation and development of performing mechanical systems of the informatized product type, that represent the main method to increase the potential of energy conservation, has required the introduction of new optimization criteria and radical improvement solutions of dynamic quality. The general interest, in the case of the transmission of movement on the mechanical systemic to obtain efficiency as high as possible next to the ideal one.

IOP Conf. Series: Materials Science and Engineering **514** (2019) 012017 doi:10.1088/1757-899X/514/1/012017

These for the transmission of the movement of rotation the highest efficiency, a series of restrictions are imposed such as the weight, cinematic or the degrees of loading the technological ones referring to the quality of execution [2].

At the electromechanical actuator appear spatial restrictions referring to conditions of transmission of the movement (auto breaking, speed) and also technological or the execution etc. The effect of the constraints can be put in evidence by the situations in which the optimization can be done only from the point view of only one criterion, example of the minimum weigh, minimum volume or maximum efficiency resulting in constructions with axial very big and radial dimensions. The constrains in the maximization of the efficiency, taking into consideration mainly the functional conditions are of a special importance in stating the problem of optimization and in achieving the functionality of systems. In the papers on are going to present some main restrictions which affect the maximization of the mechatronic efficiency in the case of rotations system and of those of the linear transmission.

2. Theoretical comments

A method of solving this, taking into account the practical situation when we know the use and the destination of the linear electromechanical actuator would be the particular case of the functional method the multicriterial problem is reduced to a problem of defined by several objective functions. We gets the following definition of the problem to be optimized:

- minimizing: $U(f_1, f_2, ...f_k)$;
- under to: $g_j(x) < 0$; $j = 1, 2....m$;

Knowing the degree of importance of criterion, we give each objective function a value $0 < q < 1$, with the purpose to make a hierarchy. We can determine the best solution of the multicriterial problem by minimizing the function expressed in the following way:

$$U(x) = \sum_{j=1}^{k} \frac{q_i}{f_i\left(x^{ideal}\right)} f_i(x) \quad x \in \Omega; \tag{1}$$

where:

x^{ideal} represents the best point of each objective function;

q - coefficient that represent the weights given to deferent objective functions on the functions of degree of importance.

The sum of these weights should be: $\Sigma q_i = 1$

In these conditions, starting from a certain point from the inside of the field Ω of the allowable we can try the improvement of the value on the criterion without training a serious deterioration of each of them. The reasoning is available only in the given situation of a good knowledge of the use and the performances imposed by according to the world technical level as well as the development tendencies. In the case of the linear electromechanical actuator we raise the problem of the optimization of the construction under an acting moment and this should the following criteria:

- minimum mass F_1;
- minimum exterior diameters F_2;
- minimum distortion at torsion F_3.

By applying the example known in the specialty literature called Pareto's problem, the final expression of the optimization problem is:

- minimizing $F_1 = f_m(x) = M = M(d, l, z_s, \beta_n, p, r_0)$ [mm^3];
- minimizing $F_2 = f_9(x) = D_{ext.} = D(m, b, z_3, \propto)$ [mm];
- minimizing $F_3 = f_M(x) = M_{fr.} = M_f(F. p, \eta)$ [daN·m];

under:

- conditions of resistance at torsion;
- geometrical conditions.

The solution to the problem depends on a better mathematical expression value of each criterion

3. **The formulation of problem of optimization**

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The optimization model, presented in figure 2, is characterized by the existence of mutually conflicting criteria and these optimum solution in relation to the one objective functions. The optimum can be described as follows, knowing the extremal of the objective function we can obtain the optimization solution for each criterion separately and the desired solution is one in solving multicriteria optimization problems it is almost impossible to define explicitly in advance the peripheries regarding the selection of the best design. In such circumstances the most suitable procedure is along a method with an interactive encroaching, in which the decision maker takes gradual decisions. The interactive method is based upon a dialogue between the designer and the computer in the process of finishing the best compromising solution [7]. The optimized parameters obtained after the global optimization are taking into account when we establish the technical solution of the correlated mechanic systems and of this destination. Because of the contradictory action of some parameters, we'll give priority to a certain criterion but only after knowing the actual working conditions next comes the systemic optimization. He facts presented a bow have a qualitative character it is not permitted the quantitative of the degree of importance and the subjective selection of the degree of importance for each criterion in general and the selection of the criteria. These results the necessity of using one of the developed techniques of analysis in the value engineering called the imposed decision. This method allows by comparison between optimization criteria, to establish the degree of importance for all the optimization criteria taken in info analysis**.**

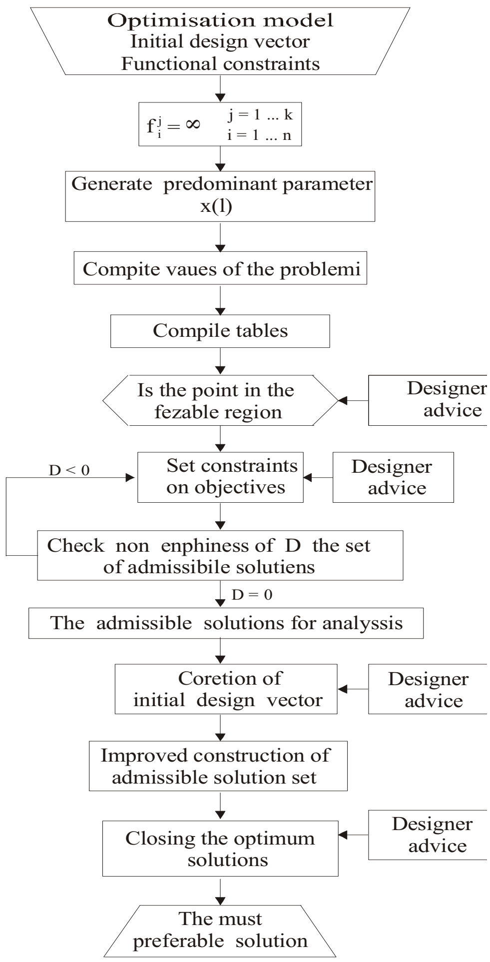

Figure 2. The iterative algorithm for optimisation

4. The operation model for optimization

The practical development of full optimization formula is hard to achier for a great number of objective functions. For a kinematics structure of screw servo driver mechanism with balls the formulation of an optimization model supposes first of all, the defining of the objective functions simultaneously with the internal and extremely constraints as within a complex mechanical system. For the kinematics relation in figure 1, the optimization solution throat simultaneous leasing or increasing of objective function: dynamic capacity, - axial rigidity - the outer speed of the screw, -the position precision: - life duration,- volume of material used for screw, the dissipation a power through scrubbing, - the information capacity: The criteria corresponding for the desired performances have the expression according to the functional criterion for the best system as extreme of the function [3].

In order to develop an optimization patterns according to very strict engineering requirement it is necessary the introduction of a number of performance criterion and the formulation of some appropriate objective functions. The mathematical pattern for the problem of the multicriteria optimization consists in nonlinear programming methods of function as in the following relation:

There is a vector:

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$$x = [x_1, x_2, x_3, \quad , x_n]^{q}, \tag{2}$$

which has to satisfy the functional constraints under of inequality:

$$g_{i}(x) < 0, \quad i = 1, 2 \quad m; \tag{3}$$

of equality

$$h_{i}(x) = 0, \quad i = m + 1, \quad p.$$

and the vector function to be optimized

$$f\{x\} = [f_1\{x\} \ldots\ldots f_k\{x\}]^{q} \tag{4}$$

where:

$$x = [x_1, x_2, \quad , x_n]^{q}$$

is a vector in n dimension in the space Euclidian R^n, $m, n, p, k \in$ N.

In many engineering optimization problems there often exist several no commensurable criteria, which must be considered. This solution is formulated as multicriteria optimization problem in which the engineer's goal is to maximize or minimize not a single but several functions at the same time [7]. In developing an optimization model, one must start with very strict engineering requirements, which a planetary gear train should fulfilling regarding the efficiency, volume, factor of safety, weight of the planetary gear train, peripheral of the planets, frictional loss power etc. [5]

The criterions' regarding the desired performance is expressed by the functions which, for the best planetary gear train should reach the extreme:

$$Extreme\ x \in D.\ f\{x\} = 0, \tag{5}$$

The following relation defines the domain:

$$\mathrm{D} = \mathrm{x} \in \left\{ \mathrm{R}^{\mathrm{n}} \right\} \left| \mathrm{g(x)} < 0 \wedge \mathrm{h(x)} = 0 \right| . \tag{6}$$

Based on the objective functions given and on the functional constraints, all the relevant values of the screw - servo driver mechanism in rolling elements, so that the vector of the variable values can be written in the form of the following relations.

The variable design vector is identified with:

$$\bar{x} = [p, r_c, d_b, z_s, \beta_n]^{q}. \tag{7}$$

The functions of the criterion for a mechanic transmission of the screw with rolling elements can be written as it follows:

- outer diameter:

$$f_1(x) = d = \sqrt{\frac{4 \cdot \beta \cdot F}{\pi \cdot \sigma_{ac}}} \quad [\text{mm}], \tag{8}$$

- axial rigidity:

$$f_2(x) = R = \Delta F / \Delta l \quad [\text{N}/\mu\text{m}], \tag{9}$$

- volume of material used for screw

$$f_3(x) = V = V(d, l, z_s, \beta_n, p, r_0) \quad [\text{mm}^3], \tag{10}$$

- the outer speed of the screw:

$$f_4(x) = n_{crt.} = 402 \cdot 10^3 \cdot a^2 \cdot d_m / l^2 \quad [\text{rot/min}], \tag{11}$$

- the manufacturing precision:

$$f_5(x) = p = \sum \Delta p_a / l = \sum \Delta p / l + j_{max} \ [\mu\text{m}], \tag{12}$$

- the frictional moment:

$$f_6(x) = M_{fr} = F \cdot V \cdot 10^3 / 2\pi \cdot \eta \quad [\text{daNm}], \tag{13}$$

- mechanical efficiency:

$$f_7(x) = \eta = \text{tg}\ \beta_m / \text{tg}\ (\beta_m + \varphi) \quad [\%], \tag{14}$$

- the transmission ratios:

$$f_8(x) = i_m = \text{tg}\ \beta_n\ [/], \tag{15}$$

- axial rigidity:

$$f_{10}(x) = d_s = \sqrt{\frac{64 \cdot F \cdot l_f^2 \cdot c_f}{\pi^3 \cdot E}} \quad [\text{mm}], \tag{16}$$

- the bending stress:

$$f_{11}(x)=\sigma_{ech}=\sqrt{\left(\frac{4\cdot F}{\pi\cdot d^2}\right)^2+\left(\frac{2\cdot M_f}{0{,}2\cdot d^3}\right)^2}\ \text{[daN/mm}^2\text{]} \tag{17}$$

- the information capacity:

$$f_{12}(x)=I_d=\log_z S^n \tag{18}$$

- life duration:

$$f_{13}(x)=L_h=\sqrt{\frac{F_m}{C}}\ \text{[ore]} \tag{19}$$

The vector to be optimized $\bar{x}$ = $[p,\ r_c,\ d_b,\ z_s,\ \beta_n]^q$ that will satisfy the inequality constrains respectively from or respectively, equations from the

- contact stress:

$$g_1(x) = s_C = \sigma_a - \sigma_{0a} > 0\ [daN/mm^2], \tag{20}$$

where:

$$\sigma_a = (2{,}3 \div 3{,}0)\cdot 10^3\ \mu \cdot p_a,$$

$$\sigma_{0a}=0{,}388\cdot\sqrt{\frac{F_N\cdot E_{ech}^2}{R_{ech}^2}},$$

- safety factor for bending stress:

$$g_2(x) = s_F = \frac{\sigma_a}{\sigma_{ech}} - 1{,}5 > 0, \tag{21}$$

- safety factor axial rigidity:

$$g_3(x) = s_H = \frac{\sigma_a}{\sigma_{cr} t} - (0{,}5 - 0{,}8) > 0, \tag{22}$$

- safety factor for outer speed:

$$g_4(x) = s_n = \frac{n_a}{n_{crt}} - 0{,}8 > 0, \tag{23}$$

- the efficiency:

$$g_5(x) = s_e = \frac{P_a}{P_{crt}} - (0{,}80 - 0{,}99) > 0, \tag{24}$$

- life duration:

$$g_6(x) = s_L = L_{conv} - L_{necesar} > 0, \tag{25}$$

- the position precision:

$$g_7(x)=s_p=\frac{\Delta p_a}{l}-\frac{\Delta p_{\max}}{l}\le 0, \tag{26}$$

- the manufacturing:

$$g_8(x) = D_{cb\ min} \ge \frac{L}{K_a}, \tag{27}$$

where: Δp şi K_a according to the table 1

Table 1. Parameter values Δp şi K_a

Δp	0,003	0,005	0,010	0,015	0,025
K_a	25	35	50	65	90

which has to the constructive constraints as in the following

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$$\frac{d_b}{D_{cb}} = 0{,}07 \div 0{,}20\,; \qquad d_b = (0{,}55 \div 0{,}65)\, p, \tag{28}$$

$$\frac{r_b}{r_f} = 0{,}90 \div 0{,}98\,; \qquad r_f = (0{,}515 \div 0{,}526)\, d_b.$$

5. The configuration of the experimental stand

Future development could also be optimizing from the point of view of regulating and controlling motion control parameters using fuzzy logistics based on vague crowds. In order to improve and to study the possibilities of regulating and control of the actuator movement a new research direction has been tried using complex systems of data acquiring and analysis by means fuzzy logistics [6]. Thus, a configuration has been used whose pattern is presented in figure 2. As it results from the pattern in hardware configuration, there are the following components whose main characteristics are presented in figure 3: linear actuator 1, traducer 2, and data acquisition board 3 (number of channels, maximum speed of sampling, data transfer); account unit 4 (microprocessor, memory, video screen), actuator interface and board of fuzzy logistics [5].

Figure 3. The stand of industrial linear

6. Conclusions

The multicriteria optimization method solves the problem of selection of optimum parameters constructive and functional of the linear electromechanical actuator. To define the multicriterial optimization model for linear mechanical electromechanical actuators, a computer program based on an interactive dialogue was developed using a new algorithm. The best comprising solution obtained through the method of the importance of the criteria of objective function gives the optimum functional parameters. The constraints are defined to find the basic constructive parameters which defined have to by simultaneous optimized, through objectively severe functions. Following the application of this methodology, we have found optimal solutions for linear electromechanical actuators using a new advanced motion control logistics. There are new developments of electromechanical linear actuators both in terms of configuration and their programming.

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