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THEORETICAL AND PRACTICAL STUDY ON THE ELABORATION OF AN OPTIMIZATION PROGRAM OF DIMENSION CHAINS

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Abstract: The technical and economic aspects of solving dimension chains have been and still are a very difficult problem because the designing engineer does not have all the necessary data available to him. This paper presents a methodology which helps us in determining the economic tolerances of the elements of a complex dimension chain. The calculation algorithm of economic tolerances proposed by this methodology consists of 8 steps. In order to apply the solving methodology of complex dimension chains and determine economic tolerances this paper presents a case study of a complex dimension chain that forms at the design and assembly of a tapered gear. Based on this algorithm, a logical scheme was made and based on it a calculation program of economic tolerances was elaborated. The program was elaborated in C++ language and applies to any personal computer compatible with I.B.M –PC.

1. INTRODUCTION

We know that determining the tolerances for the diameters of shafts and bores is simpler because the dimension chain consists of only three elements, and the execution conditions for shafts and bores are known. In exchange, determining the tolerances for non-diametral dimensions of the pieces that are part of the dimension chain with a large number of elements is much more complex, because difficulties occur, like for instance [2]: the lack of quantitative technical prescriptions for subassemblies, assemblies, mechanisms and machines; dependence of some technical prescriptions on a large number of parameters both in use and in manufacturing; variable number of elements that take part in dimension chains; the need to consider certain characteristics valid only for a certain case, etc.

In time, solving methods for complex dimension chains have appeared. These calculation methods of dimension tolerances with several elements manage to connect the error that occurs in the closing element of the dimension chain with the errors of the respective chain. By applying this correlation, we can determine the value of the closing element error of the dimension chain. This calculation method is a direct calculation method of the dimension chain. Most of the times, solving the reverse problem of dimension chains is required. This calculation is called design calculation and has to be made during the product designing stage [2]. Experimental researches correlated with the industrial practice have lead to the conclusion that the dependence between the relative cost of the piece depending on the processing accuracy is of the form of a hyperbole, fig.1 [2].

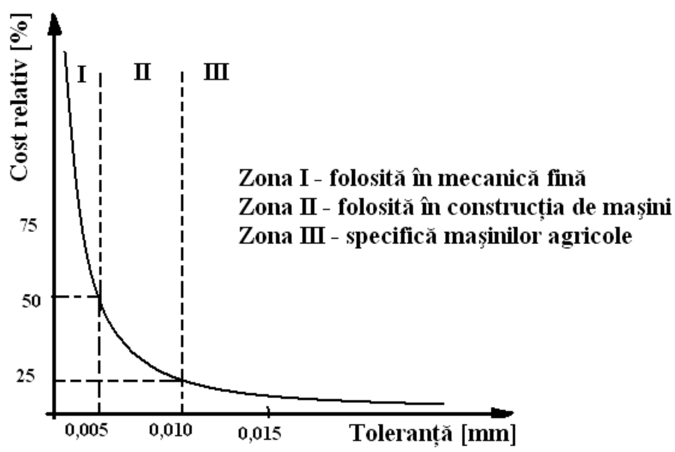

Fig.1. Relative cost-processing accuracy dependence

2. METHODOLOGY REGARDING THE ELABORATION OF CALCULATION AND OPTIMIZATION PROGRAM OF DIMENSION CHAINS

In order to determine the proposed methodology, the problem of optimizing the tolerances of the dimension chain elements agreement around the average tolerance value occurred. In this sense, we have to find the relations that determine the economic statistic tolerances of the primary elements of the studied dimension chain [2].

Determining the tolerance of the resulting element of a dimension chain, through the statistic method, is made with the following relation:

$$T_R = \frac{1}{k_R}\sqrt{\sum_i \left(k_i^2 \sum_j T_{ij}^2\right)} \qquad 1$$

For some of the primary elements of the dimension chain, the size of the tolerance is established from specific manufacturing conditions. Let's note the square sum of these tolerances with S:

$$S = \left[\sum_i \left(k_i^2 \sum_l T_{il}^2\right)\right] \qquad 2$$

Introducing the relation 2 into the relation 1 we get:

$$k_R^2 (T_R)^2 - S = \sum_i k_i^2 \sum_j T_{ij}^2 \qquad 3$$

The processing cost of a primary element of the dimension chain depends on its tolerance and on other factors like the nominal dimension, the surface of the processed surface as well as on other factors that we note with b_{ij}. The cost will be given by the relation:

$$C_{ij} = f_{ij}(T_{ij}, b_{ij}) \qquad 4$$

The total cost of all the processing operations of the primary elements is:

$$\sum C_{ij} = \sum\sum C_{ij} = \sum\sum f_{ij}(T_{ij}, b_{ij}) \qquad 5$$

In order to get the minimal value, we use Lagrange's method of non-determining factors. A new relation is written including relations 5 and 3:

$$\theta = \sum_i \sum_j f_{ij}(T_{ij}, b_{ij}) + \lambda \sum_i k_i^2 \sum_j T_{ij}^2 \qquad 6$$

where: λ is Lagrange's factor.

In order to get the minimal value, the 1st order partial derivates of the function θ become equal to 0:

$$\frac{\partial \theta}{\partial T_{ij}} = f'_{ij}(T_{ij}, b_{ij}) + 2\lambda k_i^2 T_{ij} = 0 \qquad 7$$

For the primary elements, the following tolerances result:

$$T_{ij} = -\frac{f'_{ij}(T_{ij}, b_{ij})}{2\lambda k_i^2} \qquad 8$$

In order to determine Lagrange's factor, expression 8 is replaced in 3 and it results:

$$k_R^2 (T_R)^2 - S = \left(\frac{1}{2\lambda}\right)^2 \sum_i \left[\frac{1}{k_i^2} \sum_j \left(f'_{ij}(T_{ij}, b_{ij})\right)^2\right] \qquad 9$$

Therefore:

$$2\lambda = \frac{\sqrt{\sum_i \left[\frac{1}{k_i^2} \sum_j \left(f'_{ij}(T_{ij}, b_{ij})\right)^2\right]}}{\sqrt{k_R^2 (T_R)^2 - S}} \qquad 10$$

Replacing relation 10 in relation 8 we get:

$$T_{ij} = \frac{f_{ij}(T_{ij}, b_{ij})\sqrt{K_R^2(T_R^2) - S}}{K_i^2\sqrt{\sum_i\left[\frac{1}{K_i^2}\sum\left(f_{ij}(T_{ij}, b_{ij})\right)^2\right]}} \qquad 11$$

The processing cost depends on the provided tolerance and on other factors and it is given by the relation:

$$C_{ij} = d_j + v_{ij} \cdot T_{ij} \qquad 12$$

Through derivation we get:

$$\frac{\partial C_{ij}}{\partial T_j} = f_{ij}(T_{ij}, b_{ij}) = v_{ij} \qquad 13$$

Replacing in relation 11 we get:

$$T_{ij} = \frac{|v_{ij}|\sqrt{K_R^2 T_R^2 - S}}{K_i^2\sqrt{\sum_i\left[\frac{1}{K_i^2}\sum v_{ij}^2\right]}} \qquad 14$$

where: v_{ij} is the variation intensity of the processing cost of the primary element j; K_R – relative spreading coefficient of the resulting element; T_R – tolerance of the resulting element; K_i – relative spreading coefficient for the i dimensional repartition; S – square sum of the primary elements tolerances of the dimension chain for which the size of these tolerances is required by the manufacturing specific conditions.

The first partial derivate $\frac{\partial C_j}{\partial T_j} = V_j$, can be replaced with the ratio of some finite increases, meaning we can write:

$$V_j = \frac{\Delta C_j}{\Delta T_j} = \frac{C_j^F - C_j^I}{T_j^F - T_j^I} \qquad 15$$

where: C_j^F is the cost of the processing operation of the primary element j for tolerance T_j^F;

C_j^I - processing cost of the primary element j for tolerance T_j^I.

In order to determine the cost variation intensity v_j we have to determine the value of the processing cost first, that is:

$$C_j = C_m\left(t_a + \frac{t_{pî}}{n_l} + \frac{t_{sc}}{n_t} + t_{bo}\right) + \frac{C_s}{n_t} \text{ lei} \qquad 16$$

In which

[illegible]

where: C_m labour costs, service and machine-tool amortization (lei/min); t_a additional time; $t_{pî}$ –closing preparing time; n_l – number of pieces from the batch; t_{bo} – main operation time; C_{sc} - cutting tool costs; C_a – machine-tool amortization costs; S_t – worker's salary; R_g – service costs; M_u – machine-tool value; N_a – number of amortization years of the machine-tool; C_r – capital repairs quota; F_t – annual time fund; N_z – number of working days; N_s – number of shifts per day; N_h – number of hours per shift; T – cutting tool life.

3. ALGORITHM OF THE CALCULATION AND OPTIMIZATION PROGRAM OF DIMENSION CHAINS

Based on what we mentioned above, a calculation algorithm will be established consisting of the following steps [3]:

a. Establishing the number of primary elements in the dimension chain.
b. Establishing the dimensional repartition of the resulting element.
c. Establishing the dimensional repartition for every primary element.

d. Statistic average tolerance calculation for the primary elements of the dimension chain based on relation 1.
e. Establishing the necessary data for the processing cost of every primary element for two processing variants.
f. Processing cost calculation for every primary element separately in the two variants, with the help of relation 16.
g. Economic tolerance calculation of primary elements, with the relation 14.
h. Results checking. If the economic tolerances calculated for the primary elements result in the tolerance required for the resulting element of the chain.

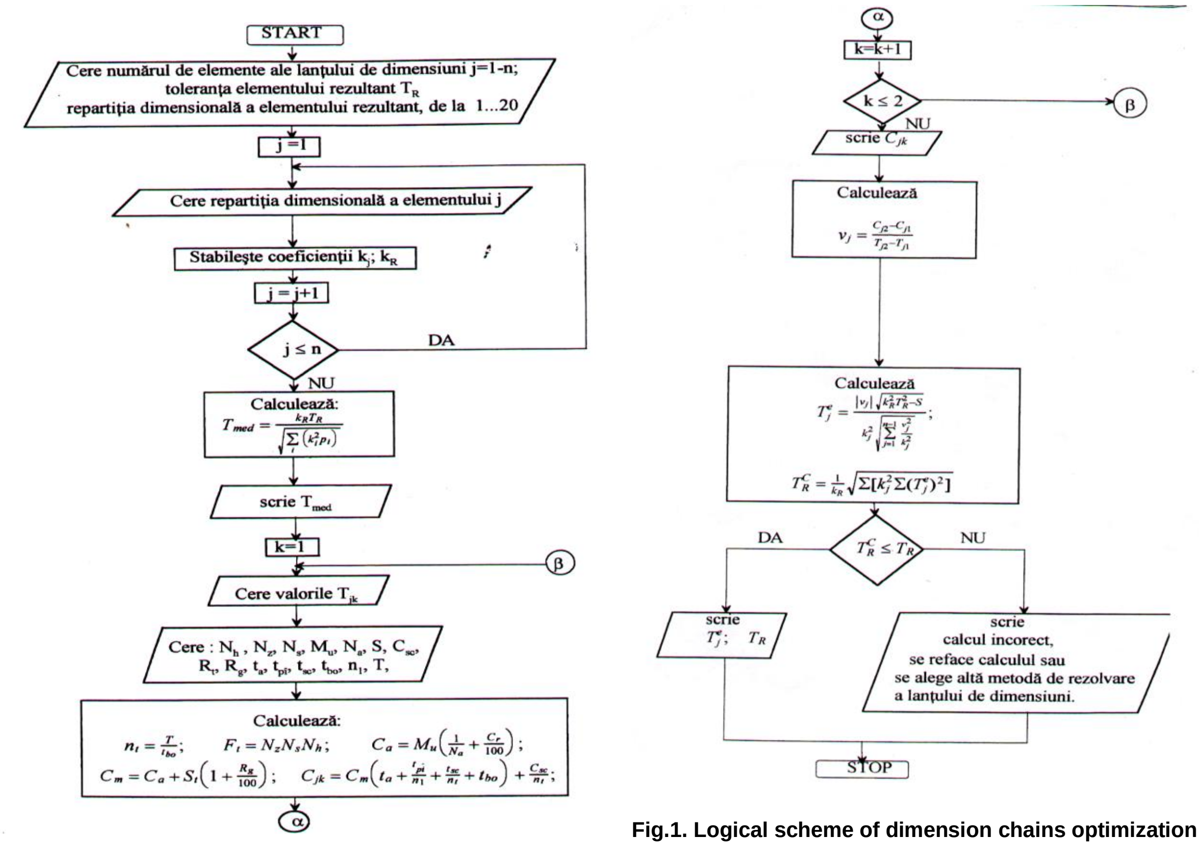

Fig.1. Logical scheme of dimension chains optimization solution.

Based on the presented algorithm, the logical scheme was traced for elaborating a computer program. A calculation program of economic tolerances was made in C++ language, compatible with any PC –I.B.M. A case study for which the program will be used is described in the second part of the paper, namely: determining the economic tolerances of a complex dimension chain formed at the design and assembly of a tapered gear reducer.

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