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SYSTEM FOR CUTTING CONDITIONS OPTIMIZATION OF MACHINING

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ABSTRACT : A computer system comprising a technique and software for cutting conditions optimization of machining work-pieces has been developed. The technique is based on factor space scanning with coordinates: feeding and cutting speed. The optimization is carried out in terms of net cost and productivity and requires knowledge of the dependencies of physical constraints upon the cutting conditions elements as well as the overall costs per work-place and cutting tools. The developed software for cutting conditions optimization offers a variant of "complete recording" in which all admissible combinations of the conditions. The respective target function values of the constraint parameters are recorded in an output file. A numerical example for demonstrating the system potentials has been solved and conclusions have been drawn concerning its applications to a concrete work-place.

Keywords: Optimization; Cutting conditions; Cost; Productivity; Durability; Tool; Machine.

TALAŞLI İŞLEMEDE KESME KOŞULLARININ OPTİMİZASYONU İÇİN BİR SİSTEM

ÖZET : İş parçalarının talaşlı işlemesinde kesme koşullarının optimizasyonu için bir teknik ve yazılımdan oluşan bir bilgisayar sistemi geliştirilmiştir. Söz konusu teknik kesme ve ilerleme hızlarıyla oluşturulan faktör uzayını esas almaktadır. Optimizasyon süreci net maliyet ve üretkenlik terimleri kullanılarak yürütülür ve işyeri başına ortalama maliyet ve kesici takım maliyetleri kadar kesme koşulları unsurlarının üzerindeki fiziksel sınırlamalara olan bağımlılıkların bilinmesini de gerektirir. Kesme koşullarının optimizasyonu için geliştirilen yazılım, koşulların akla gelebilecek tüm kombinasyonlarında tam kayıtlarının alınabilmesini sağlamaktadır. Sınırlayıcı parametrelerin göreceli hedef fonksiyon değerleri bir çıktı dosyası halinde kaydedilebilmektedir. Sistemin kabiliyetlerinin gösterilmesi için sayısal bir örnek çözümü yapılmış ve gelişmiş bir işyerine uygulanabilirliği ile ilgili saptamalarda bulunulmuştur.

Anahtar Kelimeler : Optimizasyon; Kesme Koşulları; Maliyet; Üretkenlik; Dayanıklılık; Takım; Tezgah.

INTRODUCTION

A great variety of material types which follow various requirements of the treated surface are being machined in industry. To this end, cutting tools and machines having various operation characteristics and cost are being used. In practice, there is a great number of possible combinations of cutting conditions according to the potentials of machines, tools and operating conditions. It is necessary to make a concrete decision for each work-place ensuring optimum outcomes of machining regarding net cost or productivity, observing a number of constraints.

For rough machining the restraints are imposed to obtain the desired tool durability and power conditions for maximum allowable power or forces, transmitted from the major or feed drives of the machine. For precise machining the constraints result from the desired tool durability and the machined surface roughness [1].

Cutting conditions optimization is possible to achieve for certain models of the process major characteristics expressing the target functions dependencies and physical constraints of conditions elements: depth of cut a_p, speed v_c and feed f (f_z, f_n). A number of optimization methods are known: gradientless, gradient, of experimental optimization, of optimization with regional and functional constraints, single-parameter and multi-purpose optimization, methods of linear [2,3] and non-linear programming [4]. In the models of cutting conditions optimization the real costs per work-place and cutting tools have to be considered.

The objective of this paper is to develop a computer system for multi-parameter optimization of cutting conditions during machining regarding the production net cost, productivity and machining time.

MATERIALS AND METHODS

EXPERIMENTAL STUDY

CONDITIONS FOR THE IMPLEMENTATION OF THE SYSTEM

In order to prepare the input data introduction in an appropriate manner so that the work-place features are shown, it is necessary to know certain initial conditions related to the choice already made of machine, tool type and size and machined surface.

Machine and work-place characteristics

Depending on the machine design, the costs per work-place R_1, EUR/min are defined including the machine price, labour cost, power consumption, premises area, etc.

Tool characteristics

Depending on the tool type and size chosen (single point cutting tool, milling cutter, drill, etc.) the costs per tool R_2 , EUR are determined in relation to one cutting edge, including the price of the tool, of the cutting insert, of tool recovery, replacement time t, min, etc.

Characteristics of the machined surface

-materials, hardness, mechanical strength;

-dimensions (rotation surface having length L mm and diameter D mm, plane having width B mm and length L mm).

Factor and target function values constraints

-minimum and maximum values of feed f $(f_n, f_z)_{min}$, f $(f_n, f_z)_{max}$ and cutting speed v_{cmin}, v_{cmax}, m/min, limiting the factor space where the target function optimum values are found.;

-minimum guaranteed tool life [T], min;

-power constraints of the major drive [P], kW in terms of the allowable cutting force $[F_c]$ or the feed drive [F], N;

-maximum arithmetical average roughness of the machined surface [Ra], μm;

-minimum manufacturing net cost As, EUR, minimum machining time t_m, min, or maximum productivity θ, work-pieces/min;

-minimum guaranteed productivity expressed by the number of workpieces per minute [θ] or by the machining time t_m, at appropriate manufacturing cost, or maximum allowable net cost [A_s] at suitable productivity (when the operation is a critical point in the manufacturing process).

INTRODUCTION THE MODEL CHARACTERISTICS OF THE CUTTING PROCESS

The implemented optimization technique requires knowledge of the target function models of net cost and productivity (machining time) and the constraints according to 1.4 depending on the factors whose values should be optimized, in this case, the cutting conditions values. Catalogues and user's manuals show these models most frequently by exponent dependencies of individually acting factors. The summarized relations, comprising all machining processes are of the type [4]:

-for tool life:

$$T = C_T v_c^{n_T} f^{y_T} a_p^{x_T} d^{z_T} z^{r_T} b^{u_T} K_T ; \qquad (1)$$

-for cutting force:

$$F_c = C_{F_c} v_c^{n_{F_c}} f^{y_{F_c}} a_p^{x_{F_c}} d^{z_{F_c}} z^{r_{F_c}} b^{u_{F_c}} K_{F_c} ; \qquad (2)$$

-for machined surface roughness:

$$R_a = C_{R_a} v_c^{n_{R_a}} f^{y_{R_a}} a_p^{x_{R_a}} K_{R_a} , \qquad (3)$$

where: C... are constants; v_c, a_p and f are elements of the cutting conditions; n..., y... and x... are exponents showing the impact of the cutting conditions elements on the corresponding characteristics of the cutting process, d is the diameter of milling cutter, drill, etc. z is the number of teeth, b is the milling width, and z..., v... and u... are exponents showing their impact; K... are the correcting coefficients, indicating the concrete operating conditions.

In some partitive studies the above characteristics also indicate possible compound impact of factors. In order to make the computation part of the program general-purpose, it has been envisaged, all relations represented in the form (1...3) to be transformed to:

$$\ln y = b_0 + b_1 \ln v_c + b_2 \ln f + b_3 \ln a_p + b_4 \ln v_c \ln f + b_5 \ln v_c \ln a_p + b_6 \ln f \ln a_p + b_7 \ln v_c \ln f \ln a_p , \qquad (4)$$

where y is the corresponding function of the constraints: tool life T, force F, power P or roughness R_a, but when the impact of the three factors is independent, the coefficients $b_{i...}$ in front of the terms, indicating the compound impact, receive zero values.

Preparation of target function models

The following functions can be used as target functions:

-the time for machining a surface t_m, min, determined by the relation

$$t_m = K_t \frac{L}{v_c f} , \qquad (5)$$

where K_t is a coefficient depending on the type of machining ($K_t=10^{-3}\pi D$ - turning, drilling, counterboring and reaming; $K_t=10^{-3}\pi D z^{-1}$ milling, etc. [1]);

-productivity θ, items/min, determined by the relation:

$$\theta = \frac{1}{t_m + t_s \frac{t_m}{T}} ; \qquad (6)$$

-manufacturing net cost of the operation, determined by the relation:

$$A_s = \frac{C_1}{v_c f} + \frac{C_2}{v_c^{n_T+1} f^{y_T+1}} , \qquad (7)$$

where C_1 and C_2 are constants dependent on the type of the process of cutting [1].

Optimization program structure

An optimization program in Pascal has been developed based on the technique of scanning the area limited by the minimum and maximum values of feed $f_{min}...f_{max}$ and cutting speed $v_{cmin}...v_{cmax}$, having a scanning step along both coordinate axes of factor space Δf and Δv_c. The simplified flowchart of the optimization program is shown in Fig. 1.

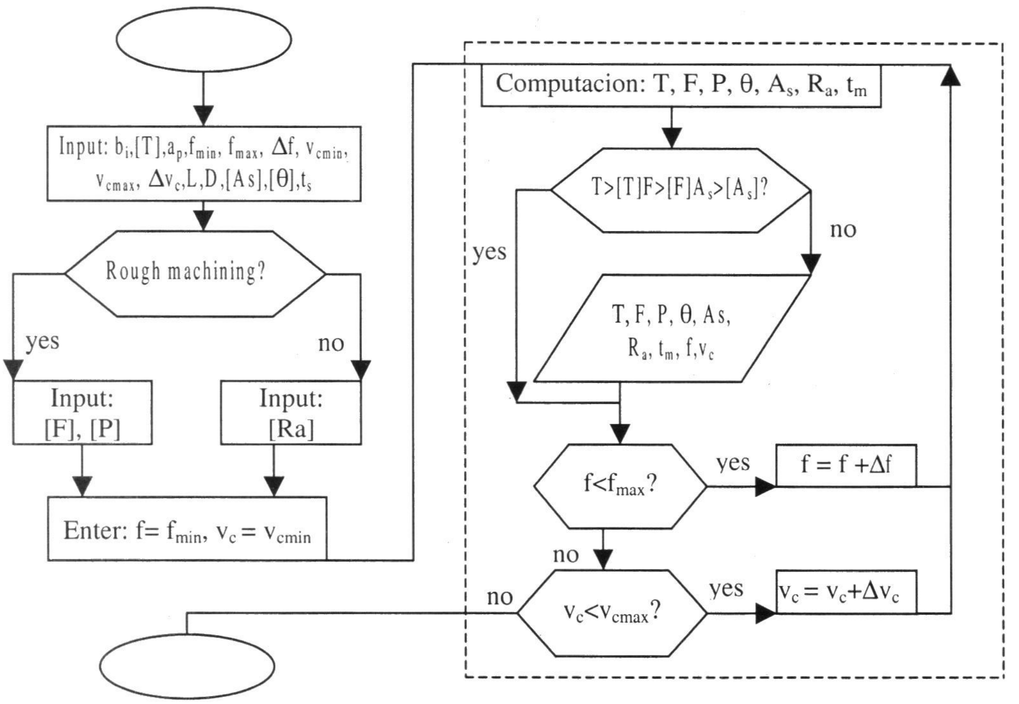

Figure 1. Simplified flowchart of the program

The coefficients b_i... of the physical constraint models y (4) are entered as input data. If necessary, the limit values of the first target function A_s or θ (t_m) can be entered, provided that optimum values of the other function are sought. The depth of cut is entered in view of single-stroke machining. If several tool strokes are necessary, optimization is done for each of them.

In the subroutine all the points of factor space are scanned. For each of them, the parameter values of constraints and target functions are calculated and compared to the corresponding admissible values. When all constraints are satisfied, the instantaneous values of the target functions, constraint parameters and the respective elements of the operating conditions are recorded in an output file.

The program is set to work in a few variants. The 'complete recording' variant provides as a result, a list of values of A_s, θ, t_m, T, F, P, Ra and the respective values of f and v_c at all points of scanning where constraints are met. The analysis of these values enables us to draw conclusions about the role of the prevailing constraints and to recommend ways of changing the initial machining conditions. For example, if the constraints are mainly on Ra, a tool having a larger radius of the tool point r_ε , can be used, if they are on allowable power or force, the machine could be changed, etc. This variant allows the analysis of single impact of certain factors - elements of operating conditions, etc., on target functions or constraints.

The 'optimum value recording' variant shows the coordinates of a point in factor space v_c – f and the respective values of the two target functions A_s or θ (t_m) in cases of constraint or no constraint on the values of one of the target functions variant allows the analysis of single impact of certain factors - elements of operating conditions, etc., on target functions or constraints.

The 'optimum value recording' variant shows the coordinates of a point in factor space v_c – f and the respective values of the two target functions A_s or θ (t_m) in cases of constraint or no constraint on the values of one of the target functions.

A NUMERICAL EXAMPLE

Cutting conditions optimization when turning a workpiece of steel 5XHM (GOST 5950-63), of dimensions D=100 mm, L=200 mm, on lathe C11T.10 design, using a knife with an insert SNMM120408 P25 (ISO 1832-1985) and costs of work-place exploitation R_1=0,108 EUR/min, and costs per a single cutting edge of the knife R_2=0,615 EUR and depth of cut of 2.5 mm. For the operation turning the constants C_1 and C_2 from formula (7) are defined by the relation: $C_1=10^{-3}\pi DLR_1$ and $C_2 = \frac{C_1}{C_T}(t_s + \frac{R_2}{R_1})$.

Physical constraints: [T]=10 min, [F]=4000 N, t_s=2min, f_{min}=0.3 mm/rev, f_{max}=0.6 mm/rev, v_{cmin}=100 m/min, v_{cmax}=250 m/min. The steps used for scanning the factors are: Δf=0.05 mm/rev and Δv_c=25 m/min.

The constraint models in accordance with dependencies (1) and (2) are of the form [5]:

$$T = 297.10^6 a_p^{-0,5} f^{-1,267} v_c^{-3,333} \tag{8}$$

$$F_c = 3700 a_p^{0,87} f^{0,75} v_c^{-0,1} \tag{9}$$

After transforming the models into the models into the form (4), the coefficient values are obtained:

-in the model for lnT $b_0 = 19.51$ $b_1 = -0.5$ $b_2 = -1.267$ $b_3 = -3.333$ $b_{12} = b_{13} = b_{23} = b_{123} = 0$;

-in the model for lnF $b_0 = 8.216$ $b_1 = 0.87$ $b_2 = 0.75$ $b_3 = -0.1$ $b_{12} = b_{13} = b_{23} = b_{123} = 0$.

DISCUSSION

- Cutting conditions optimization techniques have been analyzed when the target function models and the constraints on various operations of machining materials are known and the scanning technique has been accepted as suitable for accomplishing the objective set.
- A general-purpose approach to model preparation of various types with independent and compound impact of factors has been recommended.
- Software for mode optimization in terms of cost and productivity has been developed having variants of options for obtaining output results.
- The optimum operating conditions for the four possible variants of outcomes have the following factor and target function values:
  - Minimum net cost

For the 'complete recording ' variant it has been ascertained that for the conditions parameter variation range, the manufacturing net cost varies form 0.104 to 0.236 EUR/min. The minimum net cost is achieved for cutting conditions v_c= 150 m/min, f=0.6 mm/rev, and the productivity is 1.3 work-pieces/min, and the machining time is 0.698 min. Data analysis has shown that feed plays the major role in obtaining better results. By its increase the net cost decreases and this is more strongly expressed at lower cutting speeds (Fig. 2.a). When the cutting speed is increased, the net cost decreases, passes through a certain minimum and then it rises slightly. This tendency is stronger for the lower values of feed (Fig. 2.b).

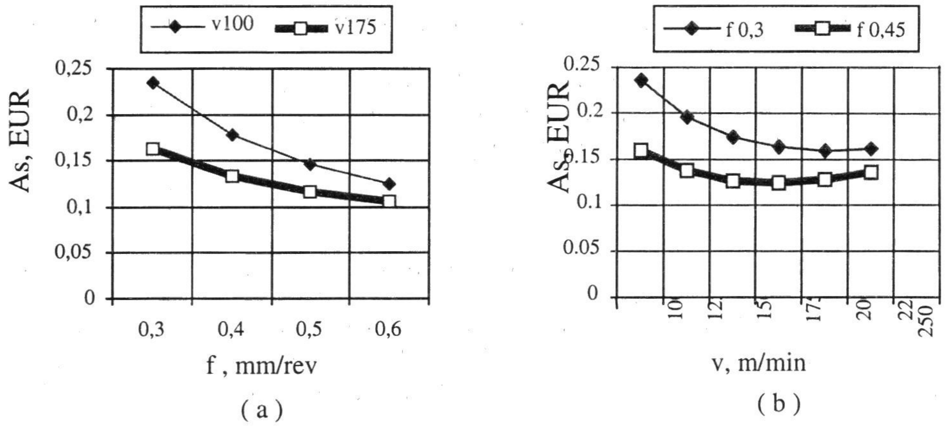

Figure 2. Dependency of A_s on: a) feed , b) cutting speed

- Maximum productivity

For the 'complete recording' variant it has been ascertained that for the conditions parameters variations range the machining time varies from 0.65 to 2.09 min and productivity - form 0.47 to 1.4 work-pieces/min. Maximum productivity is reached at cutting conditions: v_c=175 m/min, f=0.6 mm/rev. The respective net cost value is 0. 106 EUR.

Data analysis shows that productivity θ increases monotonously with the increase in speed and the feed and the functions do not obtain extremums.

- For each concrete case it is necessary to analyze and specify the cost components per work-place and tools, directly affecting the efficiency of the optimization being carried out, so that the results of the implementation of the software to be still more reliable.

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