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CUTTING CONDITIONS OPTIMIZATION TAKING INTO ACCOUNT THE COST COMPONENTS PER WORK-PLACE

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ABSTRACT : Techniques of detailed calculation of the cost components concerning the service of work-place and tool required to determine the cutting conditions, for which the production costs are minimum, have been proposed. Two groups of costs are calculated and conditions parameters ensuring the best outcomes of machining in terms of economy are determined by means of the software product that has been developed having interaction mode. Interim and end results needed to carry out respective analyses and to make well-grounded decisions can be visualized on a monitor, recorded in files and printed. A concrete example of turning using two machines and two tools has been considered. The potentials of the techniques and software for analyzing the work-place and impact of tool cost components on manufacturing net cost have been demonstrated.

Key Words*:* Optimization, Cutting conditions, Net cost, Productivity, Expenses, Work-place, Tool, Machine.

BİRİM İŞYERİ İÇİN MALİYET UNSURLARINI DİKKATE ALAN KESME KOŞULLARI OPTİMİZASYONU

ÖZET : Üretim maliyetlerinin minimum olduğu kesme koşullarının belirlenmesi için gereken takım ve işyeri hizmeti ile ilgili maliyet unsurlarının ayrıntılı hesaplama teknikleri önerilmektedir. Karşılıklı etkileşimi olan geliştirilmiş yazılım yardımıyla; iki maliyet grubu hesaplanmış, talaşlı işlemenin en ekonomik olduğu koşullar belirlenmiştir. Sorumlu analizler yapabilmek ve işe yarar kararlar alabilmek için gereken süreçler ve nihai sonuçlar, bir monitörden gözlenebilir, dosyalara kaydedilebilir ve print edilebilir durumdadır. İki tezgah ve takım kullanılarak yapılan ayrıntılı bir tornalama örneği verilmektedir. Takım maliyeti unsurlarının üretimin üzerindeki etkisini ve işyerinin analizi için, önerilen tekniğin ve yazılımın potansiyeli gösterilmiştir.

Anahtar Sözcükler*:* Optimizasyon, Kesme Koşulları, Net Maliyet, Üretkenlik, Masraflar, İşyeri, Takım, Tezgah.

INTRODUCTION

Work-pieces of various shapes and dimensions are machined on various machines using tools of various types, capacity and price. The objective of machining is to provide the required accuracy and quality of machined surfaces. In the conditions of competitive economy they should be ensured at minimum net cost of machining and at productivity sufficient to enable the manufacture of the machined batch for a certain period of time.

Cutting conditions are usually optimized by the above parameters: net cost and productivity, under a number physical constraints: minimum tool life of the tool [T], allowable cutting forces: principal [F_c] and feed [F_f], maximum power rate [P] or roughness of the machined surfaces [Ra] [1].

Optimization solution models usually comprise the costs of the work-place and tools as taken for granted. When such an approach is taken the calculated values of the conditions elements are close to maximum feed and in the range of relatively high cutting speeds, allowable by the constraints imposed, and the reserves offered by the well-founded choice of work-place and tool are not used.

In most cases within a firm an order can be filled at work-places of various technical or economic characteristics - machines significantly differing in price, dimension setting-up time, tools and conditions, tools of various number of cutting edges, geometry, tool materials and recovery costs referring to one cutting edge etc. To make the outcomes of the cutting conditions optimization adequately precise, the cost of the work-place and tool cost should be considered not as constants but as files of the same economic structure resulting from national and corporate financial standards, which differ for each work-place. The techniques of cutting conditions optimization taking into account the cost components per work-place should allow target function analysis taking into consideration the concrete potentials of each work-place, to recommend not only conditions but well-grounded work-places and tools as well. The objective of this paper is to develop techniques of cutting conditions optimizations during machining by net cost and productivity enabling the analysis of the individual characteristics of the work-place.

MATERIALS AND METHODS

The implementation of techniques and software for output parameters optimization within a certain firm having work-places of various characteristics require definite data structuring by creating a constant data base for each work-place and also by entering variable data on each new batch of work-pieces which are to be machined.

Structure Of The Constant Data Base

A certain part of the production costs is related to the state financial policy as: type and amount of taxes and company financial policy as the cost of labour, heating, lighting, the organization of determining the cost per work-place in a certain unit of the firm. Another part is related to previous information about prices of tools and their cutting elements, number of their cutting edges and their exploitation potentials.

Costs per work-place R_1.

The comprise labour costs A_1 and cost related to the machine A_2, determined by the formula:

$$R_1 = A_1 + A_2 \text{, EUR/min.} \quad (1)$$

Labour cost A_1, EUR/min is determined by the dependency

$$A_1 = A_{11}\left(1 + \frac{A_{12} + A_{13}}{100}\right), \quad (2)$$

where A_{11} is the money wage, EUR/min, A_{12} is the addition to it, %, A_{13} are taxes and social security contributions, %, (for Bulgaria: health, retirement, re-training and unemployment).

The costs related to the machine A_2, EU/min are determined by the dependencies

$$A_2 = A_{21} + A_{22} + A_{23} + A_{24}, \quad (3)$$

where depreciation and repair cost A_{21}, working area maintenance cost A_{22}, power consumption cost A_{23} and additional materials cost (oils, coolants, etc.) A_{24} are determined using the equations below.

The cost of depreciation and repair of machines is

$$A_{21} = \frac{S_m}{60\tau_m Q\eta_n}(1 + \frac{K_R}{100}), \quad (4)$$

where S_m, EUR/min is the price of the machine, τ_m is the term of recovery of the machine cost given in years, Q is the annual sum of working hours, η_n is a coefficient showing the amount of time using the machine within the working day, %, K_R is the cost of repair as percentage of the machine price.

The cost of working area maintenance is:

$$A_{22} = \frac{F_m A_{221}}{60Q}, \quad (5)$$

where F_m, m^2 is the area required to place and service the machine and A_{221}, EUR/m^2/year is the cost of production area comprising the cost of lighting, heating, compressed air, current repairs of the premises, etc. The latter are included as averaged statistical data from a previous period of time.

Power consumption cost is determined by the formula:

$$A_{23} = \frac{S_{el}}{60}\sum_{i=1}^{n}\frac{P_i K_{1i} K_{2i}}{\eta_i}, \quad (6)$$

where S_e is the price of electric power per 1 kWh, P_i is the power consumed by the i^{th} electric motor, η_i is its efficiency factor, K_{1i} is its utilization time factor during a shift, and K_{2i} is the utilization power factor.

The cost of additional materials is determined by:

$$A_{24} = \frac{1}{60Q}\sum_{i=1}^{n}\Omega_i K_i S_i, \quad (7)$$

where Ω_i, kg/year, is the yearly expenditure rate of additional materials of the i^{th} type, K_i is a coefficient allowing for the loss of materials of the i^{th} type, and S_i is its price. A_{24} is usually adopted after averaged statistical data from a previous period of time.

- **Tool cost**

It is appropriate to determine the tool cost of one cutting edge, i.e. for a length of time equal to the tool durability which is a function of the cutting conditions .

The dependencies differ in case of resharpenable tools and tools having replaceable cutting parts which cannot be resharpened.

The cost of tools having replaceable cutting parts which cannot be resharpened R_2,, EUR is:

$$R_2 = \frac{n_z R_{21}}{n_{T1}} + \frac{R_{22}}{n_{T2}} + \frac{R_{23}}{n_{T3}} + R_h, \quad (8)$$

where n_z is the number of inserts used simultaneously, R_{21}, EUR is the price of one insert, n_{T1} is the number of its cutting edges, R_{22}, EUR is the price of the tool body, n_{T2} is the length of utilization of the body, expressed in the number of cutting edges, R_{23}, EUR is the cost of spare parts for the tool, n_{T3} is the length of utilization of spare parts expressed in the number of cutting edges, R_h, EUR, is the cost of preset adjustment of the tool.

The cost of resharpenable tools R_2^*, EUR can be determined by the dependency:

$$R_2^* = \frac{R_{21}^* - S_{21}^* + n_s R_s^*}{n_s + 1} + R_h, \quad (9)$$

where R_{21}, EUR is the price of the tool, S_{21}, EUR is its residual cost, n_s is the number of resharpenings, R_s, EUR is the price of one resharpening.

Techniques of cutting conditions optimization have been developed taking into consideration the cost components per work-place and software Borland Pascal based on the method of scanning the area limited by the minimum and maximum values of cutting speed V_{cmin}, V_{cmax} and feed f_{min}, f_{max} and scanning pitch along both axes Δv_c and Δf.

A simplified flow-chart of the program is shown in Fig.1. In the data base, the cost structure R_1 and R_2 is input and it is constant but the cost components have variable values for various work-places, tools and cutting conditions. It contains the physical constraint models of optimizations already carried out, data on available machines, machined work-pieces and tools used, which is something established. The data base is open to new variants. It is advisable that the expedience of tool usage should be checked more frequently as the most flexible element of the production process by means of optimization. The program allows the analysis of the expected efficiency of new machines, instead of the available ones, before purchasing them.

The input data are formalized and coded in a suitable manner. The coefficients of the physical constraint models T, F, P, Ra for the respective type of machining (rough or fine) are entered as input data and models are previously prepared in a convenient flexible form [2] .

When the net cost values above a certain limit $[A_s]$ and productivity values below a certain limit $[\theta]$ are unacceptable, these values of the target functions can be assumed to be physical constraints. The machined surface dimensions, depth of cut a_p, time for changing tools t_s, boundary values of feed and cutting speed, variation steps of conditions elements within the factor space are entered as input data.

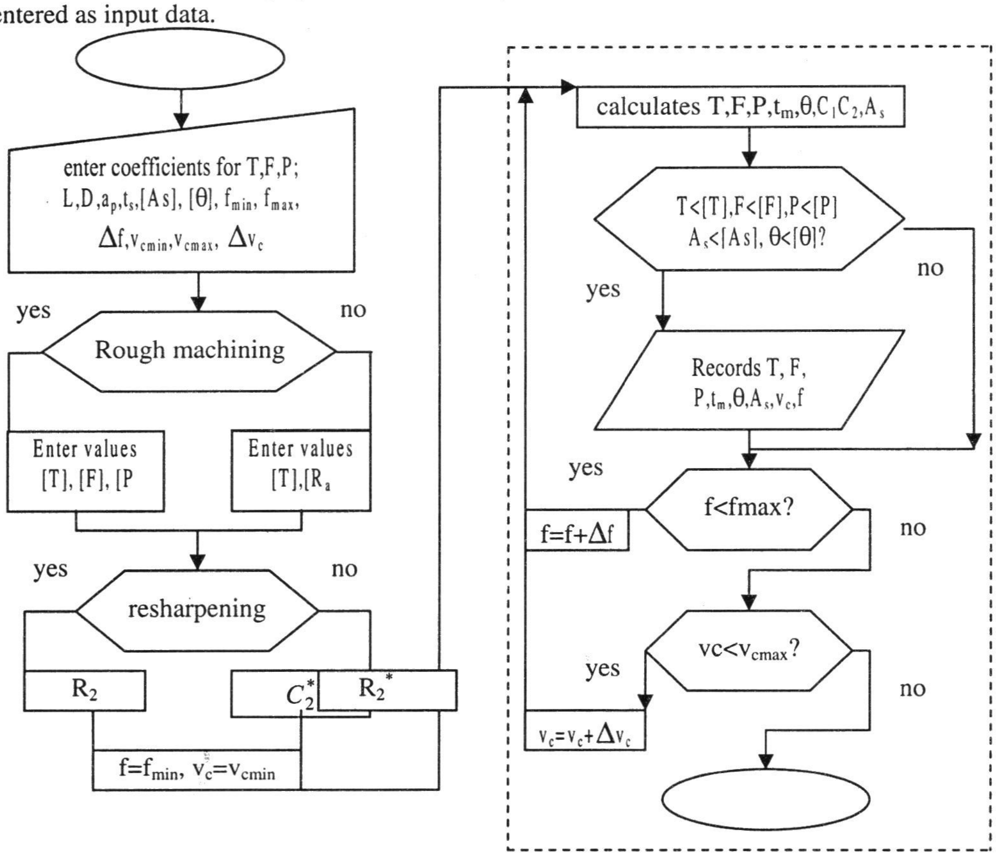

Figure1. Simplified flow-chart

To be able to calculate the instantaneous values of the physical constraints, the respective models are included in the system, relating them to the cutting conditions elements of the type y = f(v_c,f,a_p), where y are the physical constraints. They are taken from reference books, research reports and can reflect the independent or compound impact of cutting conditions parameters on the constraint functions. A more detailed study of the constraint and target functions dependencies of the cutting conditions elements is presented in [2].

All variable values of cost per work-place R_1(1) and tool R_2(8) or R_2^* (9) should be entered in the input data-prices and area for usable machines, power, force and speed constraints for each machine type, price and number of cutting edges or number of resharpenings of tools. Most of the cost components are constant for a certain firm, for instance the cost of maintaining 1 m^2 area of a certain workshop, wages, consumables for a certain type of machine, etc. and they are described in the software data base.

For each "machine-tool" combination the program should be started and given a new solution and when comparing the results, the analysis should give the best combination. When machines and tools have already been selected the introduction of some cost components R_1 and R_2 as input factors can result in finding such component values leading to better final results. In this way it can be decided whether a more expensive and durable cutting insert is more effective, whether it is profitable to use less expensive machines requiring more expenses for consumables and more adjustments, what the effect of moving production to a region of lower labour cost schemes and taxes would be, etc.

At each point of scanning for which the preset constraints are satisfied, the current values of the output parameters A_s, θ, t_m of the physical constraints T, F, P, R_a and the respective cutting conditions elements f and v_c are recorded. When using various values of the variable components of R_1 and R_2 the latter correspond to factors equivalent to the cutting conditions and their impact on target functions can be analyzed. Fig.1 shows such a variant.

NUMERICAL EXAMPLE

Cutting conditions optimization when turning a work-piece of steel 5XHM (GOST 5950-63) of dimensions:

D=100m, L=200mm [3] on lathes of C11T10 (m1) and C11T.80 (m2) design using cutting tool PSBNR 2525M12 and inserts SNMM120408 P25 and SNMG120408 P25, time for changing tools

t_s =2 min for depth of cut a_p =2,5 mm.

Physical constraints: [T]=10min, [F]=4000N, [P]=7kW, f_{min}=0.3mm/rev, f_{max}=0,6mm/rev, v_{cmin}=100m/min, v_{cmax}=250m/min.

The factor scanning pitches are Δf=0.05mm/rev and Δv_c=25m/min.

The constraint models are of the type [3]:

$$T = 297 a_p^{-0,5} f^{-1,267} v_c^{-3,333} 10^6 \qquad (10)$$

$$F_c = 3700 a_p^{0,87} f^{0,75} v_c^{-0,1} \qquad (11)$$

The constant cost components per work-place and tools are shown in Table 1, and those depending on the machines and tools in Table 2.

Table 1. Constant cost components per work-place and tools

A_1	A_{11}, EU	A_{12}, %	A_{13}, %
	0,015	30	52

A_2	A_{21}				A_{22}	A_{23}				A_{24}, EUR/min
	τ_m	Q	η_n	K_R	A_{221}	Se	K_1	K_2	η	
	5	2032	0,75	28	6,7	0,065	0,75	0,7	0,95	0,01

R_2	n_z	R_{21}	R_{22}	n_{T2}	R_{23}	n_{T3}	R_h

	1	2,18	12,44	300	2,57	300	0

Table 2. Variable cost components per work-place and tools.

lathe	Sm, EUR	F_m, m^2	P_i, kW	insert	n_{T1}
C11T.10	29520	5	10	SNMM120408	4
C11T.80	14200	4,5	7	SNMG120408	8

The manufacturing net cost of the operation is determined by $A_s = \frac{C_1}{v_c f} + \frac{C_2}{v_c^{n_T+1} f^{y_T+1}}$ [2]

which is presented in the form $A_s = A_{s1} + A_{s2}$, where A_{s1} is net cost related to the exploitation of the work-place, and A_{s2} is net cost primarily related to the exploitation of the tool.

The constants C_1 and C_2 are determined by $C_1 = \frac{\pi D L R_1}{1000}$ and $C_2 = \frac{C_1}{C_T}(t_s + \frac{R_2}{R_1})$ [2].

OUTCOMES AND ANALYSES

The analysis of the calculations of the four variants shows that for manufacturing net cost, the best outcomes are at maximum feed and at respective cutting speeds. The character of net cost variation depending on the cutting speed at concrete feed is shown in Fig.2.

The minimum net cost values for the four variants are shown in Fig.3. They have been obtained in the following optimum cutting conditions:

-for machine 1(R1=0,1172 EUR/min) tool 1 (R2=0,595 EUR): v_c=159m/min,f=0,6 mm/rev.
-for machine 1(R1=0,1172 EUR/min) tool 2 (R2=0,322 EUR): v_c=179m/min,f=0,6 mm/rev.
-for machine 2(R1=0,0725 EUR/min) tool 1 (R2=0,595 EUR): v_c=142m/min,f=0,6 mm/rev.
-for machine 2(R1=0,0725 EUR/min) tool 2 (R2=0,322 EUR): v_c=163m/min,f=0,6 mm/rev.

Since the implemented lathes have discrete series of rotation and feed frequencies, the concrete cutting conditions values are $n=500 min^{-1}$ and f=0,6mm/rev. Under these terms the conditions elements, which can be put into practice are v_c =157m/min and f=0,6mm/rev, are in the factor space and do not need recalculation by the program for checking feasibility of constraints.

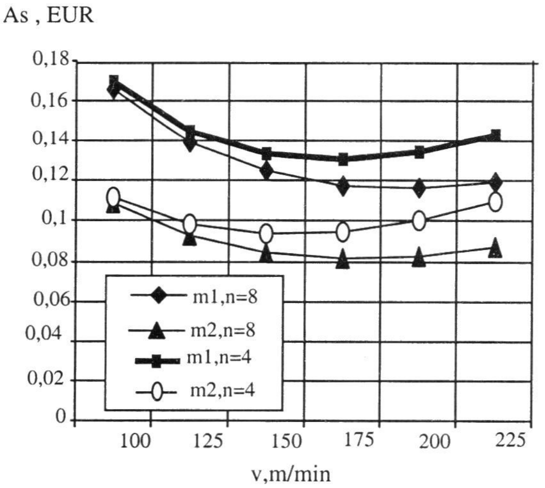

Figure 2. Impact of Vc on As for two variants of machine and tool costs.

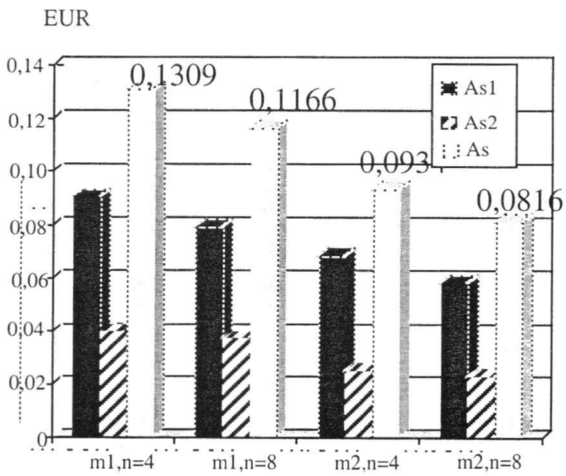

Figure 3. Optimum values of As and its components related to the work-place and tool

The practically feasible conditions are close to the determined as optimum from the four variants and as the most suitable is the implementation of machine 2 with tool 2 where the net cost is the lowest.

After outcome analysis the following conclusions can be drawn:

- The cost structure per work-place has been analyzed taking into consideration the national and company financial characteristics and specificity of each work-place. Most of the components are collected from statistical data, valid for a certain firm.
- The costs of cutting tools in variants of resharpenable and non-resharpenable designs have been analyzed.
- Techniques and software for cutting conditions optimization by cost and productivity have been developed making possible the selection of cutting conditions, machine, tool and their cost components characteristics within a certain firm or work-place to be well-grounded. When these techniques and software are employed the subjective decisions can be avoided and replaced by well-founded ones, ensuring minimum cost of machining and guaranteeing definite productivity.

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