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OPTIMIZATION OF THE PARAMETERS OF MILLING MACHINING MODE BY USING THE METHOD OF PARTICLE SWARM OPTIMIZATION(PSO)

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Aabstract: *Optimally chosen parameters of the processing mode directly influence total costs of production of a single product and therefore the profit of the company as well. In this paper, the choice of optimum parameters of the milling processing mode by using the method of particle swarm optimization (PSO) is shown. The goal of optimization is represented through the goal function (optimization function or optimization criterion) and by using the method of optimization PSO, minimum costs of machining process are obtained. Optimization function is also represented graphically for the purpose of clearer analysis on the technological area in which the values of machining mode that give minimum costs of machining process are presented.*

Keywords: *Milling, Cutting parameters, Particle Swarm Optimization*

1. INTRODUCTION

Optimization of parameters of the machining mode is the method of knowledge implementation in designing of machining process with the purpose of their analysis, improvement, and reaching a higher techno-economic analysis. A basic assumption is that the costs of machining process will be optimum if costs of machining process in all technological operations of production process are optimum as well. Mathematical model of the goal function is designed by Stanić [1] and that model of function was applied by Mečanin [2] on optimization of costs of machining process by scraping of the pin. Mathematical model of function can be applied to all elementary operations with appropriate limitations, which are different for different procedures. Goal and limitation functions should contain enough influencing factors in order to accomplish objective impact on the model of machining process.

2. MATHEMATICAL MODEL OF FUNCTION OF PROCEDURE COSTS DEPENDING ON MILLING PROCESSING MODE

Function of costs, by which, depending on the entrance into the machining system and state (condition) of the machining system, direct procedure costs are described mathematically, represents in a trihedral OSVTz the area located in the first octane, and it is always concave because parameters of the machining mode must have values bigger than zero. Its form is:

(1) $$T_Z = A_{1i} + A_{2i} \cdot V_i^{-1} \cdot S_i^{-1} + A_{3i} \cdot V_i^{\frac{1}{q_1}-1} \cdot S_i^{\frac{q_2}{q_1}-1}$$

where $i = 1,2,\ldots,n$ is a number of operations that is optimized. Geometric position of points of conditional maxima at the area of function of costs comprises in the coordinate plane OSV a hyperbole, whose arms, depending on the state(condition) of entrance into the system, asymptotically approach the coordinate axis at faster or slower rate. A set of points is used for identifying the line of optimum costs at which machining process should be managed in order to achieve maximum effects regarding the costs of machining.

Optimal levels of costs are located in the region $\{S_{\max}, V_{\min}\}$, that is, the highest levels of machining are achieved when the values of steps are maximum and when cutting speed values are minimum. Inversely, the region $\{S_{\min}, V_{\max}\}$ is characterized by relatively high level of machining costs. There are special cases $q_2 = 1$ и $q_2 > 1$. For $q_2 = 1$ the same level of costs is obtained for the entire mode area $\{S, V\}$, while in case of $q_2 > 1$ maximum effects of machining which are located in the region $\{S_{\min}, V_{\max}\}$, and minimum in the mode points $\{S_{\max}, V_{\min}\}$.

Machining beyond the curve of optimum costs, unjustifiably frequent in production practice, conditions relatively great efficiency losses, especially in mode areas $\{S_{\max}, V_{\min}\}$ and $\{S_{\min}, V_{\max}\}$, because it is under such circumstances that high costs of reproduction occur in machining process [1].

Coefficient **(parameter)** A_{1i}, is always constant since it represents basic costs in a company, which do not depend on machining parameters, but influence total price of production of products. Coefficients (**parameters)** A_{2i} i A_{3i} depend on machining mode, influence total costs of production and thus define position of minimum which cannot be smaller than value A_{1i}.

3. ALGORITHM PSO

Particle swarm optimization PSO (Figure 1) represents metaheuristic method of optimization based on agents (particles) population, which was accidentally discovered by James Kennedy and Russell Eberhart in 1995, while studying the simulation of social behaviour of bird flocking [3]. Just as it is the case with all algorithms based on population, initial particle population is generated first. Position of the particle represents vector of parameters which are optimized:

(2) $$\mathbf{x} = (x_1, x_2, \ldots, x_n)$$

or potential solution. Random position in space which is explored, as well as inital velocities, is given to each particle. After that, the value of goal function of each particle is determined, and that value is added to it as the best value for the particle in question, and the initial position becomes the best position of the particle $\mathbf{p}_{\mathbf{best}}$. When all the best values of particles are determined, the particle with the minimum value is searched, and its position becomes the best position for the entire swarm $\mathbf{p}_{\mathbf{gbest}}$. Afterwards, it needs to be checked whether the criteria of optimization are satisfied, and if they are, the obtained results are shown. If the criteria are not satisfied, new velocities and positions need to be calculated.

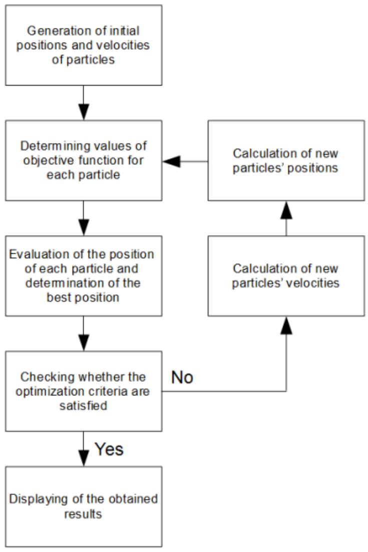

Fig.1 ***Algorithm of the method of particle swarm optimization.***

Figure 2 graphically shows how to determine new velocities and positions in two-dimensional space of search.

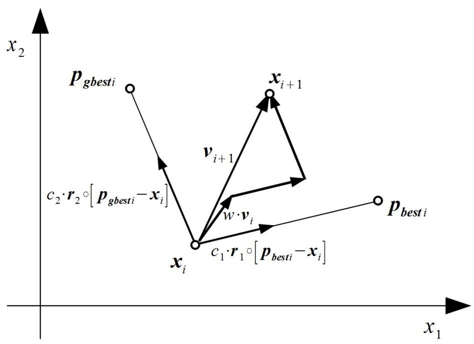

Fig.2 ***Updating of velocity and position of the i particle.***

New velocity of each particle consists of three components:

1. the component which depends on instantaneous particle velocity,
2. the component which is proportional to the distance of instantaneous position of the particle and its best value,
3. the component which is proportional to the distance of instantaneous position of the particle and its best position for the entire swarm.

(3)
$$\mathbf{v}_{i+1} = w \cdot \mathbf{v}_i + c_1 \cdot \mathbf{r}_1 \circ \left(\mathbf{p}_{\mathbf{best}\,i} - \mathbf{x}_i \right) + c_2 \cdot \mathbf{r}_2 \circ \\ \circ \left(\mathbf{p}_{\mathbf{gbest}\,i} - \mathbf{x}_i \right)$$

where w represents inertia weight, c_1, c_2 are acceleration coefficients or correction factors, $\mathbf{r}_1, \mathbf{r}_2$ represent two random vectors of the length n within the limits [0,1]. The symbol $\circ$ represents Hadamard product:

(4)
$$\left(A \circ B \right)_{i,j} = \left(A \right)_{i,j} \cdot \left(B \right)_{i,j}$$

Inertia weight w impacts the first component, and for the values in the range of 0,9 – 1,2 [4] it gives the best results, that is, the algorithm has greater chances of finding the global minimum for a reasonable number of iterations. For coefficient values which are smaller than 0,8, if algorithm finds global minimum it will find it fast. Particles in this case move quickly and it can happen that they "fly over" some area, so it can happen that they do not find global minimum. On the other side, if inertia weight has bigger value, then particles search the solution space more thoroughly and the chances of finding global minimum are greater.

Acceleration coefficients c_1 and c_2, when multiplied by random vectors $\mathbf{r}_1$ and $\mathbf{r}_2$, stochaistically manage the impact of the two other velocity components. Usually, their assumed value is approximately 2, in order for the middle value of the product of acceleration coefficient and random vector to be approximately 1. New position of the particle is determined by simple adding of the current position $\mathbf{x}_i$ and new particle velocity $\mathbf{v}_{i+1}$.

(5) $$\mathbf{x}_{i+1} = \mathbf{x}_i + \mathbf{v}_{i+1}$$

The values of the goal function for new positions of the particle are determined again, and for each particle new and old values of the goal function are compared. If the new value is smaller, then it becomes new best value and the current position becomes the best position of that particle. The position of the particle with the smaller value becomes new best position for the entire swarm. Again, it needs to be checked whether the optimization criteria are satisfied; if they are, the results are shown, and if not, the entire procedure will be repeated until the criteria are satisfied.

This is the simplest version of the algorithm of particle swarm optimization. Other versions do not have constant values for the parameters w, c_1 and c_2, but they alter by specific rules during the implementation of the algorithm. In addition, other PSO algorithms also include different swarm topologies, that is, the way in which particles in the swarm communicate.

4. GOAL AND LIMITATION FUNCTION

In this paper, 17 milling operations are optimized and in them, machining mode parameters are step $S[\text{mm/o}]$ and technological cutting speed:

(6) $$V = \frac{\pi \cdot D \cdot n}{1000}\,[\text{m/min}]$$

in which the number of rotations $n\,[\text{o/min}]$ is. They are directly related to the main processing time, so for optimum values of these parameters we have optimum time of duration of each operation, and therefore, the optimum processing time of machine part. Machine mode parameters that give minimum costs of machining process must be found within given limitations because there is a limitation by characteristics of tools and machine. Figure 3 shows 3D model of valve casing and section where the greatest number of different openings are located.

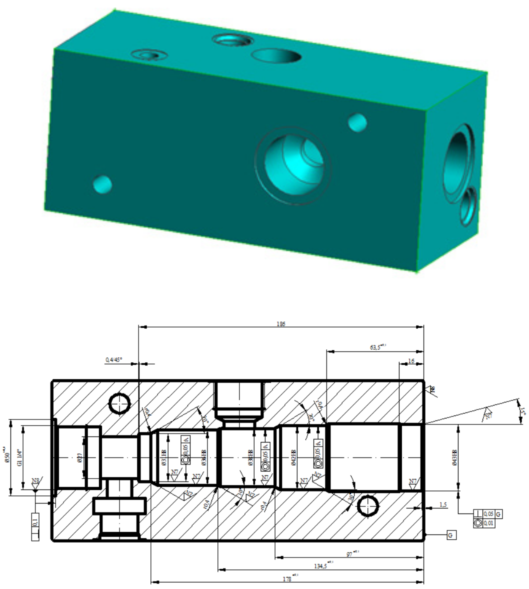

Fig.3. ***Valve casing – a machine part whose milling operations are optimized.***

Goal function which is optimized has the following form:

$$f(S_i, V_i) = \sum_{i=1}^{25} T_i$$

(7)

$$= \sum_{i=1}^{25} A_{1i} + A_{2i} \cdot V_i^{-1} \cdot S_i^{-1} + A_{3i} \cdot V_i^{\frac{1}{q_1}-1} \cdot S_i^{\frac{q_2}{q_1}-1}$$

Values of coefficients A_1, A_2, A_3, for each of 17 goal functions, are given in table 1 :

Table 1. Coefficient values A_1, A_2, A_3, a_i .

i	A_{1i} $[\text{min}]$	A_{2i} $\left[\frac{\text{din}}{\text{min}} \cdot \text{m}^2\right]$	A_{3i} $\left[\frac{\text{din} \cdot \text{min}}{\text{m}^2}\right]$	a_i $[\text{mm}]$
1	1707,801	828,8	0,748	0,2
2	1707,801	118,1	0,133	0,2
3	1707,801	14,76	0,019	0,2
4	1707,801	7,721	0,036	0,2
5	1707,801	1,505	0,007	0,2
6	1707,801	35,18	0,389	0,2
7	1707,801	1,535	0,010	0,05
8	1707,801	7,226	0,073	0,05
9	1707,801	46,33	0,486	0,05
10	1707,801	2,007	0,014	0,05
11	1707,801	81,46	0,713	0,05
12	1707,801	1,505	0,017	0,2
13	1707,801	19,48	0,671	0,05
14	1707,801	1,299	0,021	0,2
15	1707,801	137,0	1,157	0,05
16	1707,801	14,76	0,102	0,2
17	1707,801	1,612	0,252	0,05

where coefficients A_1, A_2, A_3 have the following form:

$$A_{1i} = C_{LD2} \cdot t_{reg} + C_{M7} \cdot t_{ph} + C_{LD1} \cdot \frac{t_{pz}}{n_s \cdot z} +$$

(8)

$$+\left(C_{LD1} + \sum_{i=1}^{5} C_{Mi}\right) \cdot \left(t_p + t_m + \sum t_i\right)$$

$$A_{1i} = 3\,\frac{\text{din}}{\text{min}} \cdot 480\text{ min} + 1\,\frac{\text{din}}{\text{min}} \cdot 1{,}4\text{ min} +$$

$$+3\frac{\text{din}}{\text{min}} \cdot \frac{3\text{ min}}{300 \cdot 25} + \left(3\,\frac{\text{din}}{\text{min}} + 11{,}8\,\frac{\text{din}}{\text{min}}\right) \cdot$$

$$\cdot(18\text{ min}) = 1707{,}801\,[\text{din}]$$

$$A_{11} = A_{12} = \ldots = A_{125} = 1707{,}801\,[\text{din}]$$

$$A_{2i} = \psi_i \cdot \left(C_{LD1} + \sum_{i=1}^{6} C_{Mi}\right) = \psi_i \cdot 18{,}8\left[\frac{\text{din}}{\text{min}} \cdot \text{m}^2\right]$$

(9) $$\psi_i = 10^{-6} \cdot \pi \cdot D_i \cdot i \cdot L_{0i}\,\left[\text{m}^2\right]$$

(10) $$A_{3i} = \psi_i \cdot (K_3 \cdot t_s + K_4) \cdot C_i^{-\frac{1}{q_1}}\left[\frac{\text{din} \cdot \text{min}}{\text{m}^2}\right]$$

(11) $$K_3 = \left(C_{LD1} + \sum_{i=1}^{5} C_{Mi}\right) = 14{,}8\left[\frac{\text{din}}{\text{min}}\right]$$

(12) $$K_4 = 1400\left[\frac{\text{din}}{\text{min}}\right];\; C = Q \cdot D^{q_3} \cdot a^{-q_4} k_V$$

Size Q =300 is the size of the series which is machined, kv=1,1 is the factor of the state of the machine, $q_1 = 0,75$; $q_2 = 1$ are the parameters of the machinability, $t_s = 0,15$ min is the time of the change of the tools. Values D_i, L_{0i}, ψ_i, C_i are given in the table 2 and 3.

Table 2. Values of sizes D_i, L_{0i}, ψ_i, C_i

i	D_i [mm]	L_{0i} [mm]	ψ_i [mm^2]	C_i [mm^2]
1	27	520	44,09	21922,3
2	40	50	6,280	17566,7
3	50	5	0,785	15307,1
4	21,8	6	0,411	4239,7
5	25,5	1	0,080	4093,8
6	14,9	40	1,871	1790,3
7	26	1	0,082	2993,1
8	20,4	6	0,384	1957,6
9	21,8	36	2,464	1884,3
10	34	1	0,107	2890,8
11	30	46	4,333	2261,5
12	25,5	1	0,080	1705,8
13	11	30	1,036	574,1
14	22	1	0,069	1224,7
15	40	58	7,285	2342,2
16	50	5	0,785	2870,1
17	3,9	7	0,086	126,5

A part made of steel S0545, is machined on five-axis machining center **Pinnacle LV85** (CONTROL SYSTEM: FANUC 0i-MC / 18i- MB) which has motive power of 15 Kw. Based on this fact we form the limitation which follows this goal function and refers to motive power machine , wich is 15kW , and material of the part.

(13) $0,345 \cdot S_i^{0,8} \cdot V_i < 15000 \ (i = 1,2,...,17)$

In addition to the limitation of the value of steps, technological cutting speeds must be found within boundaries given in the table 3. Values of steps must be bigger than zero and smaller than maximum reccomended values for the tool which is used in performance of milling operation. Values of technological cutting speed must also be bigger than zero and smaller than maximum velocity, which a machine is able to achieve for the appropriate diameter, that is, for the maximum number of rotations of the machine $n_M = 10000$ [o/min] is:

(14) $V_i < \frac{\pi \cdot D_i \cdot n_M}{1000}$ [m/min]

Table 3. *Upper and lower boundary values of steps and velocity :*

i	S_i [mm/o]		V_i [m/min]	
	Lower boundary	Upper boundary	Lower boundary	Upper boundary
1	0	0,08	0	508,68
2	0	0,08	0	753,60
3	0	0,08	0	942,00
4	0	0,08	0	410,71
5	0	0,08	0	480,42
6	0	0,08	0	280,72
7	0	0,08	0	489,84

8	0	0,08	0	384,34
9	0	0,08	0	410,71
10	0	0,08	0	640,56
11	0	0,08	0	565,20
12	0	0,08	0	480,42
13	0	0,08	0	207,24
14	0	0,08	0	414,48
15	0	0,08	0	753,60
16	0	0,08	0	942,00
17	0	0,08	0	73,48

5. OPTIMIZATION RESULTS

34 parameters are obtained as the results of this optimization process which represent optimum values of technological cutting speed and steps for 17 milling operations , and so the costs of these procedures have minimum value.

Optimum values of the steps ,velocity and cost price of all operations individually and collectively are given in table 4:

Table 4. *Optimum values of the steps, velocity and cost price of all operations individually.*

i	S_i [mm/o]	V_i [m/min]	T_i [din]
1	0,026	450,6	1708,29
2	0,238	625,3	1708,66
3	0,136	751,2	1708,57
4	0,012	325,3	1708,43
5	0,114	420,5	1708,21
6	0,023	240,5	1708,32
7	0,123	425,6	1710,47
8	0,030	350,4	1710,85
9	0,063	367,6	1709,96
10	0,026	560,8	1708,33
11	0,369	480,6	1708,87
12	0,119	375,4	1707,95
13	0,336	180,9	1707,88
14	0,887	350,6	1707,96
15	0,710	650,9	1707,97
16	0,600	850,6	1708,84
17	0,325	65,9	1708,94
		$\sum_{i=1}^{25} T_i$	29048,5

Number of iterations : 183

Graph of one of the 17 function costs :

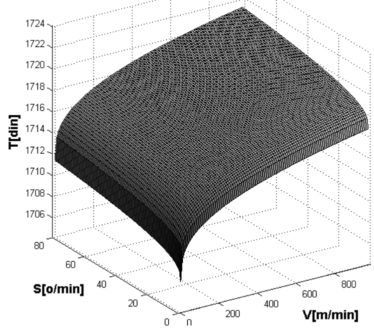

Fig.4 ***Area of the function costs of the first procedure***

According to figure we can see that the value of costs for the first operation is very close to the value 1707,8 din which represents constant cost, which means that we have reached the minimum cost , and so for the entire 17 operations, and the sum of all this costs gives us the total production price of this machine part, which is going to be minimum.

6. CONCLUSION

In this paper, the optimization of the costs of technological process of a part of a complex structure is performed by using the method PSO. For instance, in optimization of the flexible technology when real processing time is less than given, optimization of machining parameters is implemented in order to decrease costs of production. In this case, we can choose cheaper tools of lower level of cutting characteristics [5], and by using the method PSO, in a very short time, we can obtain results on which procedure allows decreasing of the machine mode and which does not, all of which can be presented in the space as in figure, for the purpose of checking of the obtained results.

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ОПТИМИЗИРАНЕ НА ПАРАМЕТРИТЕ НА РЕЖИМА НА ФРЕЗА ЧРЕЗ ИЗПОЛЗВАНЕ НА МЕТОДА НА ОПТИМИЗАЦИЯ НА МНОЖЕСТВОТО ЧАСТИЦИТЕ (PSO)

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Ключови думи: *фрезоване, рязане параметри, оптимизация на множеството частици (PSO).*

Резюме: *Оптимално избраните параметрите на обработващия режим директно влияят на общите разходи за производството на един продукт и следователно на печалбата на компанията. В този доклад е показан изборът на оптимални параметри на режим за обработка чрез фрезоване с помощта на метода на частиците рояк оптимизация (PSO). Целта на оптимизацията е представена чрез целева функция (функция за оптимизация или оптимизационен критерий) и с помощта на метода за оптимизация PSO са получени минимални разходи за процеса на обработка. Оптимизационната функция е представена също така графично за целите на по-ясен анализ на технологичната област, в която са представени стойностите на машинния режим, които дават минимални разходи за процеса на обработка.*