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OPTIMIZATION OF CUTTING PARAMETERS BY NATURE-INSPIRED ALGORITHMS

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Abstract: The surface roughness is very important factor for product quality. This paper presents an approach for determining the optimum machining parameters leading to minimum surface roughness during face milling process by nature-inspired algorithms. Face milling experiments were conducted on a vertical-spindle milling machine and experimental data were collected based on a three-factor-five-level design of experiment. The developed regression model for surface roughness was used to obtain optimal cutting parameters by nature-inspired algorithms (GA, PSO, and ACO). The analysis of this paper shows that these algorithms are capable of predicting the optimum cutting parameters.
Keywords: optimization, cutting parameters, nature-inspired algorithms

INTRODUCTION

Optimization is the process of defining the most favorable solutions for given initial conditions, from a set of possible solutions. It can be said, there is no area of human activity, system or process which cannot be optimized

A wide range of optimization methods and algorithms are used to solve the optimization parameters of cutting. Different subdivisions of these methods and algorithms can be found in the literature. Optimization algorithms can be classified into two different types by the opinion of some authors [1]: Traditional optimization algorithms (Mathematical programming; Analytical methods; Statistical methods, Adaptive methods) , and Non-traditional optimization algorithms (Genetic algorithm, Particle Swarm Optimization, Artificial Bee Colony, Ant Colony Optimization, Bat Algorithm, Firefly Algorithm, Gray Wolf Optimizer, Cuckoo Search …)

The aim of this paper is to optimize the input parameters of the face milling process by nature-inspired algorithms.

MATERIALS AND METHODS

— EXPERIMENTAL SETUP AND RESULTS

Experimental work was carried out at the Faculty of Technical Sciences, in the Laboratory for Conventional Machining. The conditions for experimental testing are given in this chapter. Conditions apply to: the workpiece material, machine tool, cutting tool and cutting conditions.

» The workpiece material

Experimental tests were carried out on aluminum alloy 7075 (Al-Zn-Mg-Cu), which was made using the conventional casting method. The workpiece has been 100 mm in width and length, and thickness 15 mm.

» Machine tool

The experimental work was carried out at the Department of Production Engineering, the Faculty of Technical Sciences in Novi Sad. The machining was conducted on a Vertical-spindle Milling Machine („Prvomajska“ FSS-GVK-3) in dry condition.

» Cutting tool

A face milling cutter with ø100 mm diameter („Jugoalat“ G.037), with cemented carbide inserts („Corun“ type SPKN 1203ED R) with tool cutting edge angle $\kappa=75°$ and rake angle $\gamma=0$.

Cutting conditions:

- Cutting speed v, or the corresponding spindle speed n,
- Feed per tooth s_1, or the corresponding feed rate s, so it is: $s= s_1 \cdot z \cdot n$, number of teeth has been $z=1$ and
- Depth of cut a.

In regard to the workpiece material and tool producer recommendations for cutting conditions, Table 1 have been presented, for a 3-factor design of experiments. All of the experiments were conducted with one insert without coolant. The mean surface roughness Ra was measured with a "Marsurf PS1" device.

Table 1 Machining parameters and their levels

Levels	Cutting speed v [m/min]	Cutting speed v [m/s]	Feed per tooth s1 [mm/tooth]	Depth of cut a [mm]	Spindle speed n
Maximum +1,41	351,86	5,864	0,223	2,6	1120
High +1	282,74	4,712	0,177	1,72	900
Midium 0	223,05	3,717	0,141	1,14	710
Low -1	175,93	2,932	0,112	0,75	560
Minimum -1,41	141,37	2,356	0,089	0,5	450

Based on the three-factor experiment plan on five levels, with each input parameter varied to five levels, a mathematical model for the mean arithmetic roughness of the machined surface was obtained, equation 2.1 [2].

24 experiments were performed, according to the Design of Experiments. The experimental results were later used to obtain a mathematical model for calculating the mean arithmetic roughness of Ra. The mathematical model is a necessary condition for the optimization of the face milling process, respectively finding optimal values of the input parameters of the processing process.

$$R_a = C v^{p_1} s_1^{p_2} a^{p_3} \exp\begin{bmatrix} p_{11}(\ln v)^2 + p_{22}(\ln s_1)^2 + \\ +p_{33}(\ln a)^2 + \\ p_{12}\ln v \ln s_1 + p_{13}\ln v \ln a \\ +p_{23}\ln s_1 \ln a \end{bmatrix} \quad (2.1)$$

Table 2. The value of the constants and exponents

C	p_1	p_2	p_3	p_{11}
201568,89	0,23366	11,20405	0,54344	-0,28380
p_{22}	p_{33}	p_{12}	p_{13}	p_{23}
2,44943	0,02290	-0,27871	-0,09218	0,27384

GENETIC ALGORITHM (GA) BACKGROUND

The GA is a search algorithm for optimization, based on a Darwinian theory of evolution and on the concept of "survival of the fittest". The basic object of the genetic algorithm is a chromosome, and the function of aim is the fitness.

The basic operators applied to chromosomes are the crossover, the mutation, and the selection. A generation is made the crossover, the mutation, and the selection, which is equivalent to one iteration in traditional optimization techniques.All genetic algorihtms function by the same principle which can be shown the most easily in further steps (Figure 1).

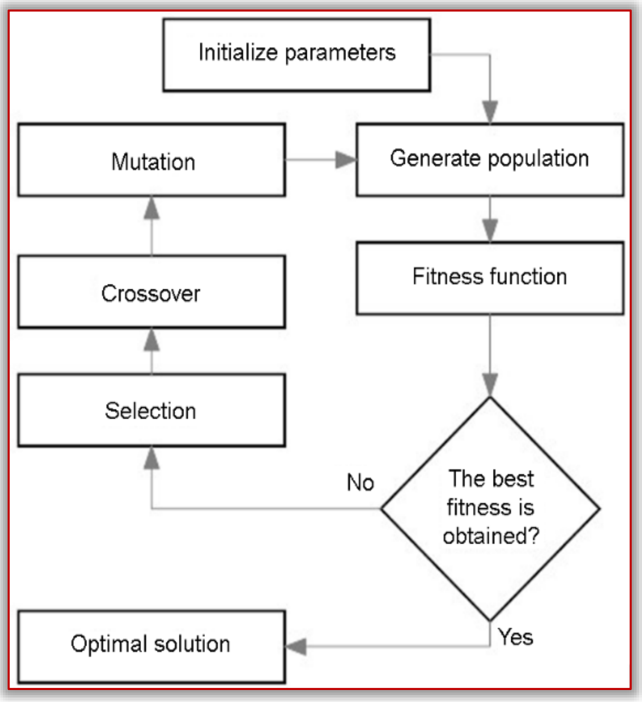

Figure 1. Methodology of GA optimization [3]

PARTICLE SWARM OPTIMIZATION (PSO) BACKGROUND

Particle Swarm Optimization (PSO) is a stochastic algorithm with population-based solution. The particle swarm optimization algorithm was detected by accident, while observing the computer simulates movements of bird flock. Reynolds C.W. in his work 1986, examined the flock of birds as a set of particles, where each particle (i.e. bird) adapts its flight to the following rules: Avoiding a collision between birds; adjusting flight speeds to closest birds and trying to stay close to other birds.

Particle swarm optimization have been successfully applied to complicated optimization of process parameters in turning (one and multiple pass), face milling (one and multiple pass), and milling, grinding. Optimal cutting speeds, feed rate, feed per tooth, depth of cut, the number of revolutions of the main spindle and the number of passes in the function of: minimum processing time, minimum processing costs, maximum process efficiency, minimum roughness of the treated surface, minimum cutting forces.

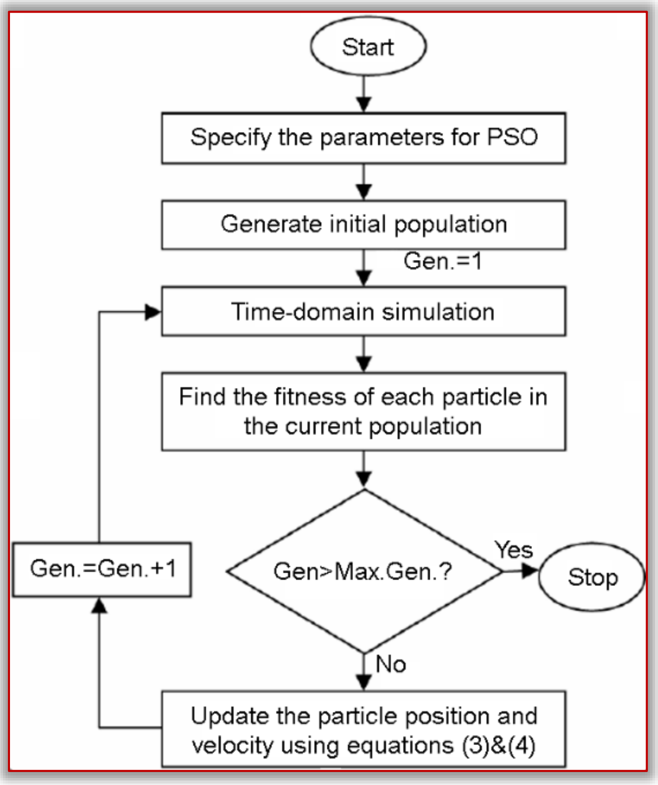

Figure 2. Methodology of PSO optimization [4]

ANT COLONY OPTIMIZATION (ACO) BACKGROUND

Ant Colony Optimization (ACO) is a population-based metaheuristic, that can be used to solve difficult optimization problems. In ACO, a set of software agents called artificial ants search for good solutions to a given optimization problem. In order to apply ACO, the optimization problem is transformed into the problem of finding the best path in the weighted graph. Artificial ants gradually build solutions by the movement along the graph. Construction process of the solution is stochastic and is based on a pheromone model, i.e. on a set of parameters associated with graph components, either nodes or edges, whose values are modified by artificial ants during the search process.

The ants, although they are blind, can find the shortest path to the food source. This feature of ants has been made available to solve real problems by using certain features and some additions.

Characteristics of ants created by artificial ant are: communication between the ants by using the chemical pheromone, preferring the roads with a higher amount of pheromones, fast increasing the amount of pheromones on short roads, than on longer ones.

Characteristics that are added to real ants: live in an environment where time is calculated discreetly, they are not completely blind and they can access to details of the problem, they can retain information for solving a specific problems with a certain amount of memory. In Fig. 3 shows the computer diagram of ACO.

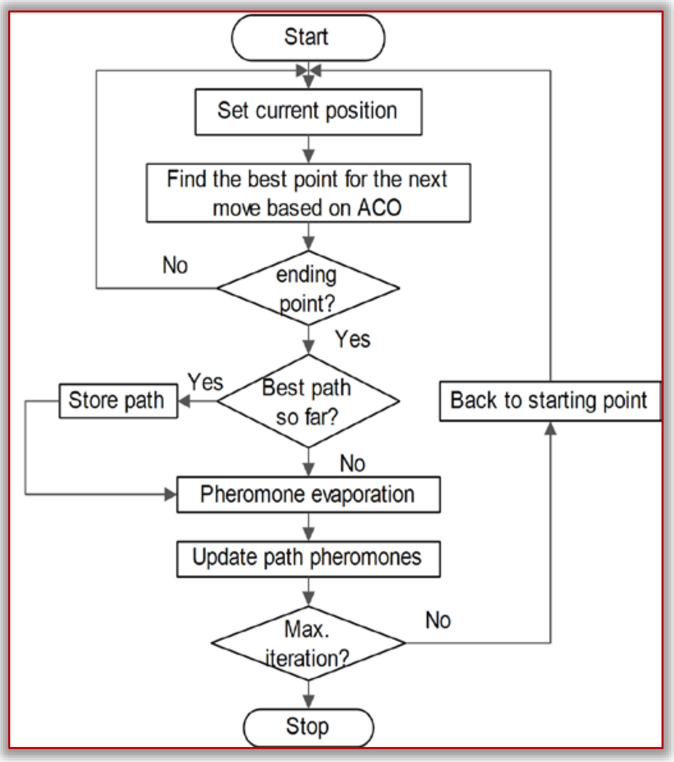

Figure 3. Methodology of ACO optimization [5]

RESULTS AND DISCUSSION

The optimization of the face milling process, or the determination of the optimum values of the cutting conditions, was carried out using various nature-inspired algorithms. Three single-criteria methods were used for this work: Genetic Algorithm – GA, Particle Swarm Optimization – PSO, and Ant Colony Optimization - ACO. The aim function in all three cases was the minimum value of mean surface roughness $\mathbf{R_a}$, respectively $(\mathbf{R_a})_{\mathbf{min}}$. The optimization process was carried out in the MATLAB software package. This software has a number of modules that allow to execute the script code for each of the optimization methods. In Table 3 is shown the limit values of the input parameters (cutting conditions).

Table 3. Limit values of input parameters

Parameters name	Minimum value	Maximum value
v [m/s]	2,356	5,864
s_1 [mm /tooth]	0,089	0,223
a [mm]	0,5	2,6

In Table 3 are presented results obtained using various optimization techniques. Optimal values of input parameters are fully matched by using different nature-inspired algorithms (ACO, PSO, and GA). Results have confirmed that nature-inspired algorithms, as useful for optimization machining processes.

Table 4. Optimal values of input parameters during the face milling process

Method	Output parameter		Optimal parameters of cutting		
			v [m/s]	s_1 [mm/z]	a [mm]
GA	R_a [µm]	0,8236	2,36	0,1011	2,6
PSO	R_a [µm]	0,8236	2,36	0,1011	2,6
ACO	R_a [µm]	0,8236	2,36	0,1011	2,6

CONCLUSION

This paper has discussed determining the optimum machining parameters leading to minimum surface roughness during face milling process by nature-inspired algorithms. Results have confirmed that nature-inspired algorithms as useful for optimization of machining processes. Some general conclusions are next:

- Preliminary experimental research is needed to form a mathematical model;
- High-quality optimization solutions cannot be expected, without a high-quality and reliable mathematical model;
- In order to perform optimization using an ant algorithm, it is necessary to introduce penal factors that allow the search space to be limited, which is not the case for the PSO;
- There is need for a script code when used some methods (PSO and ACO);
- The time of finding optimal solutions is less with the PSO method than ACO.

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