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INTELLIGENT OPTIMAL TOOL SELECTIONS FOR CNC PROGRAMMING OF MACHINE TOOLS

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Summary

The aim of this paper is to improve CNC programming of machine tools and to minimize the need for human intervention or manual inputs. The proposed optimization method for tool selection is based on a genetic algorithm. Experimental approval is done by using the Matlab environment and it has been shown that the proposed method is useful for the optimization of cutting tool selection. The reason for developing this method is to reduce human resources during the machining process, and at the same time to decrease the cost of the product, to save time and to achieve higher efficiency. This approach is called intelligent way of CNC programming.

Key words: *machine tools, intelligent, optimization of tool selection, CNC programming, Matlab*

1. Introduction

The rapid development of computer technology, the employing of CNC machines in particular, has significantly contributed to the improvement of the quality and quantity of production programmes in modern manufacturing industries. The use of an interface, which makes it possible to connect a computer to a CNC machine, directly influences the increasing capacities and accuracies of production programmes when compared to the earlier conventional CNC machines.

Nowadays, intelligent methods are being developed for use within several real applications in manufacturing industries, such as turning CNC machine tools, milling machine tools, etc. [1, 2]. The goal of this paper was to develop an algorithm for tool selection that would integrate a conventional CNC machine. In order for the intelligent method to be as reasonable as possible, the path and tool selection of the CNC machine would be optimized by the application of a Genetic Algorithm (GA). Optimizations of tool selection play an important role both for CNC machine tools or within CAD/CAM systems. Different options offered by CAD/CAM systems for tool selection are used (e.g. based on the processing method used for lathe, milling and HSC machines, tool data, tool types, tool geometries, length and diameter of tools, etc.). During machining processes, the CAD/CAM system enables quick choices regarding desired tools for manufacturing workpieces. On the other hand, without CAD/CAM systems, it is very difficult to programme CNC machines for complex geometries of workpieces.

The following describes a procedure for the selection of tools for the tool charger of a lathe and a milling machine. The procedure of selection is carried out from one tool to another but not within the range of the tool number. The developed intelligent method, which will be integrated into conventional CNC machines, enables us to select machine tools depending on the geometry of the workpiece and the commands received from the computer [3].

Chen et al. [1] presented an automatic cutting tool selection method for rough turning operations on CNC lathe machines. Their method for selecting a cutting tools procedure is made from an appropriate tool library. In order to reduce the operation time, a heuristic method is employed. This procedure ignores any request for an exhaustive operation library and the final results are very fast and efficient.

Car et.al [2] introduced optimization parameters for machining turning processes based on artificial intelligence. In order to find optimal cutting parameters, the Genetic Algorithm (GA) is used as an optimal solution. The proposed model is combined by employing the GA, and the implementation is done by using binary linear programming. The main advantages are the ability to perform the multi-object optimization and the minimizing of machining time and production costs, whilst being constrained by the technological processes and materials.

Ahmad et al. [3] describe sequences of tool selection as an important activity during process planning for milling which has a great bearing on the cost of machining. The GA formulation is used to find optimal tool sequences. Two types of selection mechanisms, i.e. "elitist selection" and "roulette method" were tested. It was found that the GA formulation generates near optimal solutions whilst reducing computation time by up to 30 % compared to the graph formulation. Their research also extended to effects of tool holders.

Balic et al. [4] applied artificial intelligence during the production process. Their concept was employed in turning operations for cutting tool selection that enabled the selection of the optimal cutting tool set on the basis of a 3D CAD model. Furthermore, an intelligent CNC programming method included a neural network (NN) and a GA was carried out. However, their system has been improved, accuracy, speed and flexibility are increased and at the same time full autonomy is reached.

Oral et al. [5] developed an optimum operation and tool sequences that are used in generative process planning systems for rotational parts. Their method is characterized by a minimum number of tool changes and minimum tool-travel time.

This paper is organized as follows: Section 1 discusses the tool selection system for turning and milling machines. Section 2 introduces an intelligent method for tool selection based on the geometry of the workpiece and crucial time of machining. Section 3 discusses the optimization by using a Genetic Algorithm. Section 4 provides conclusions.

2. Tool selection system of CNC machine tools for a turret lathe and a milling machine

This tool selection system includes the selection, management and organization of tools by CNC machines as well as all the issues concerning geometries of tools. Before the arrival of the new generation of conventional CNC machines, the operator was required to manually programme all cutting tools depending on the process of manfuacturing the workpiece. This programming was hard and often boring, and a predictive complex geometry of the workpiece was difficult to achieve.

With the application of the CAM software package it is easy to determine and programme a cutting tool based on the geometry of the workpiece. The CAD/CAM systems offer some possibilities for the solving of tool-type selection, tool path-length, type material of work-piece, type of CNC machine tools etc.

Tool selection by the CAD/CAM software is one of the more important activities of CNC programming. Recently, intelligent methods have been developed which automatically select cutting tools from a tool magazine. Various systems have been developed, but they have never completely replaced the human resource (machine operator).

2.1 Tool system of a turret lathe and a milling machine

An orientation method for selecting cutting tools in the shortest time from a tool magazine to the workpiece needs to be developed. For each manufacturing process such as turning and milling machining [7], it is necessary to choose the cutting tool for predictive geometry during the modelling of a workpiece.

In addition, there are mainly three kinds of tool changers available within the field of CNC machine tools: 1 – Tool change system with gripper arms, 2 – Tool change system magazine with chain magazine, and 3 – Tool change system with a disc magazine. The tool selection systems for milling and lathe CNC machines are presented in Fig.1.

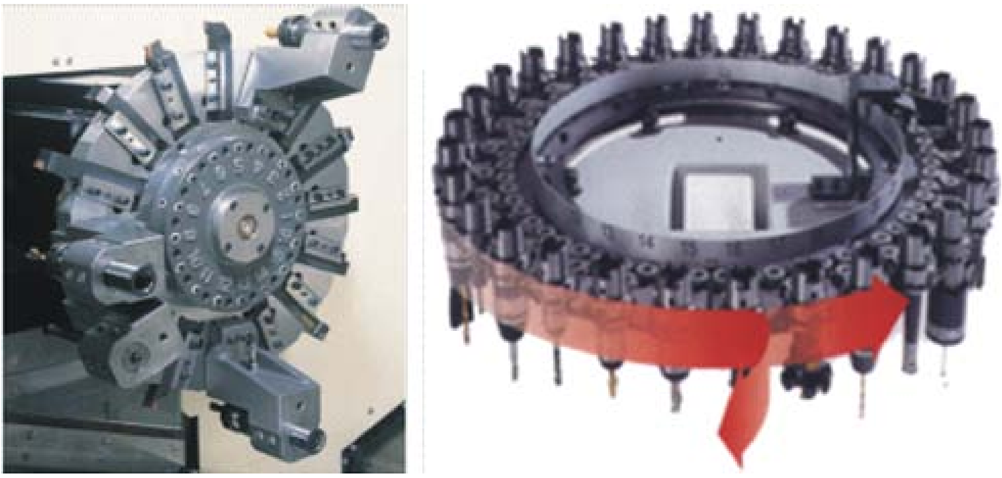

Fig. 1 Tool system: for a turret lathe (left) and for a milling machine (right) (catalogue Juraform E.K Germany)

The rotation of the tool magazine (ω - angular velocity) within the tool selection system (T) should be run in the clockwise direction. The operation of the tool magazine is graphically presented in Fig. 2.

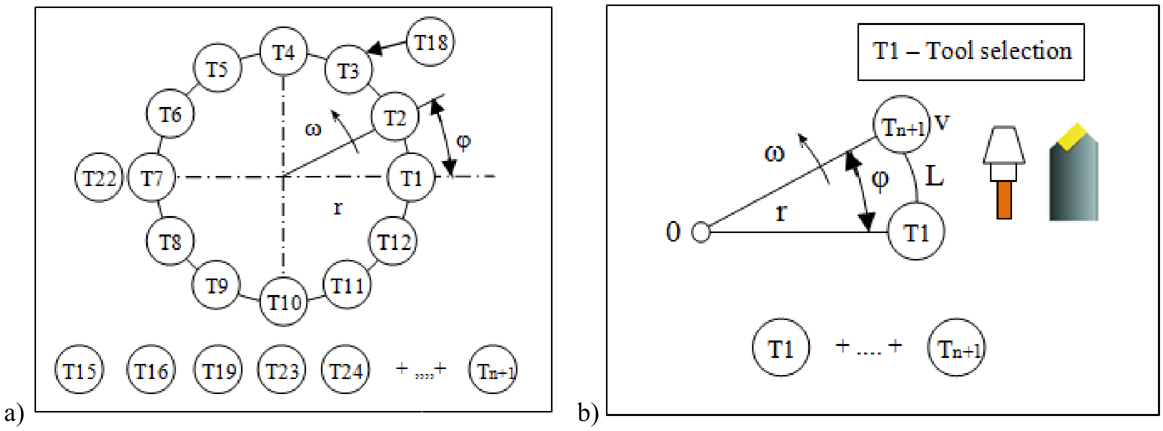

Fig. 2 a) Tool number positions during magazine tool and reserve tools selection, b) Tool selection and describing the path from one to another

The selection of a tool for the turret lathe and the total number in the magazine can be optimized based on the geometry and shape of the part. A mathematical model is generally formed for tool selection in the case of milling and lathe CNC machines, as given by the expression:

$$T_{ch} = T_1 + \cdots T_{n+1} \tag{1}$$

where (T_1) denotes the first cutting tool and (T_{n+1}) is given as the latest tool selected. The angular angles between the cutting tools for each tool can be determined by the equation:

$$\varphi = \frac{360°}{N_T} \tag{2}$$

where N_T denotes the number of cutting tools.

In order to calculate the positions of each cutting tool determined by the angular angle, it is necessary to know the number of cutting tools (N_T). If this number is $N_T = 30$, then the angular angle $\varphi = 12°$ denotes the angle between each tool.

Fig. 2 b) presents both the path (L) and the angular angle (φ) of the tool selections (T). The determinations of the path and velocity of the magazine tool are derived from Fig. 2 b), given by the expressions:

$$L = r \cdot \varphi \tag{3}$$

$$v = r \cdot \omega \tag{4}$$

When differentiating between equations (3) and (4) as functions of the angular angle (φ), and the angular velocity (ω), respectively, the equation of motion now takes this form:

$$dL = r \cdot d\varphi \tag{5}$$

$$dv = r \cdot d\omega \tag{6}$$

Expressions (5) and (6) represent the equation of motion for the magazine tool.

The crucial time during production, based on the geometry and tool selection, is given by the expression (Tm) of the magazine tool and cutting tool as follows:

$$T_m = P_{Li} \cdot \frac{D_i - d_{i-1}}{2} + N_T \cdot T_{ch} \tag{7}$$

where T_m is the crucial time, P_L is the path length of the workpiece, D_i denotes the first diameter, d_{i-1} *variety* diameter of the workpiece, T_{ch} denotes the tool selections of the magazine and cutting tools, respectively.

The target for the optimization of the tool selection is to minimize the auxiliary time and the crucial time as well as the machining time in general. The total machining time depends on the tool path length, the numbers of tools, the feed rate, the cutting speed, the depth of cutting, etc.

In order to clarify the method of intelligent tool selection during the machining operation in the cases of milling and lathe machine tools that directly influence the machinability, Table 1 below presents the application of the tool selection based on the machining process.

Table 1 Characteristics and types of tools

Tool list	*Diameter/bxh [mm]*	*Radius [mm]*	*Tool type*
T1	10	0.1	End mill
T5	15x15	2	Turn
T6	8	0.5	Ball end mill
T10	12	0.5	Drilling
T3	20x20	0.5	External
T8	16x16	-	Threading
T13	20x25	1.2	Internal

The tool list in this table refers to the number of tools, the diameter or bxh, the tool holders for lathe and milling machine tools, the radius of the tool and the tool type during machining operations, such us milling and lathe machining processes.

3. Intelligent method for tool selection for CNC machine tools

The method proposed for the intelligent tool selection will depend on certain parameters, based on the geometries of workpieces (linear, circular and spline interpolation), so that the best tool for the case of turning operation is selected and the operation is at the same time independent from the human. The application of the intelligent method for selecting the cutting tool will be based on the geometry of the workpiece (trajectory of the workpiece) for the rotational part [11].

Depending on the design of the workpiece, it can be concluded that the presented intelligent system for the cutting tool selection could be used for various shapes and for generating the tool path using CNC machines [12, 13]. The selection of cutting tool conditions is an important factor during metal cutting processes, as in the cases of lathe and milling machine tools, etc. However, direct monitoring of tool selection systems is difficult to implement because the tool selection method requires the application of the engineering methods such as Artificial Intelligence (AI).

The intelligent method depends on tool selection but could be utilized for lathe and milling machining, as shown in Fig. 3.

Fig. 3 Method of intelligent tool selection

The optimal tool selection by applying the method for intelligent systems for rotational and square workpieces with complex geometry is analysed as shown in Fig. 3. In order to operate the intelligent systems nowadays, it is necessary to optimize them by using artificial intelligence. During the development of the tool selection method, the tool path and crucial time of machining are analyzed as well.

Based on the tool selection method, the tool path trajectory is presented below, where the tool path for rough machining is presented with a red line, and the blue line represents final machining. The presented tool paths for rough and finished machining were done within the environments of Matlab, see Fig. 4.

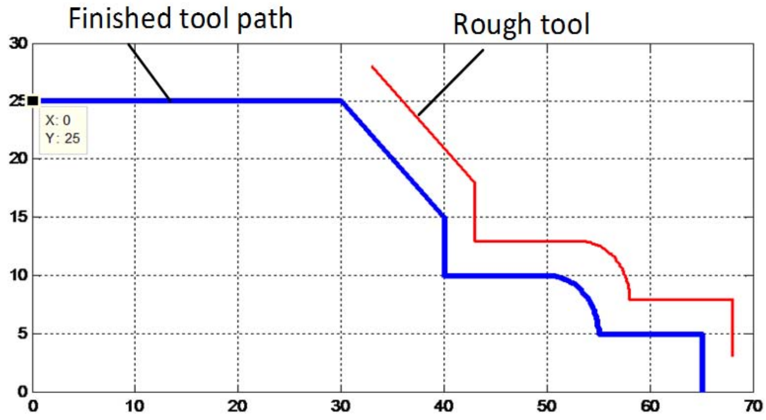

Fig. 4 Tool path based on intelligent tool selection

The tool path length depends on the tool selection method and cutting parameters. The tools are selected for 3D rotational and prismatic workpieces in order to optimize the trajectory of the path length, such as presented in the Figure above [10, 11].

4. Genetic algorithms

The genetic algorithm (GA) is one of the artificial techniques for analysis, which was invented by John Holland [9, 15]. Genetic algorithms are global search methods that are based on the evolutionary principle of natural election and genetic modifications. The work of genetic algorithms (GAs) is very popular when resolving problem optimization.

The definition of a Genetic Algorithm is that this is a stochastic method, the overall research of which mimics the natural biological metaphors of evolution. GA operates on a population of possible solutions on the principle of the survival of those individuals who are able to produce (hopefully) the best solutions possible.

Genetic algorithm is proposed for the machining process and optimization model for tool selection methodology. However, this model depends on the machining parameters and the design of the workpiece. To achieve this optimized model of tool selection, it is necessary to know the knowledge base of the machining (technological process, types of tools, etc.) as well as to find the best solutions for the machining process and tool selection. Fig. 5 presents a model for tool selection and its optimization.

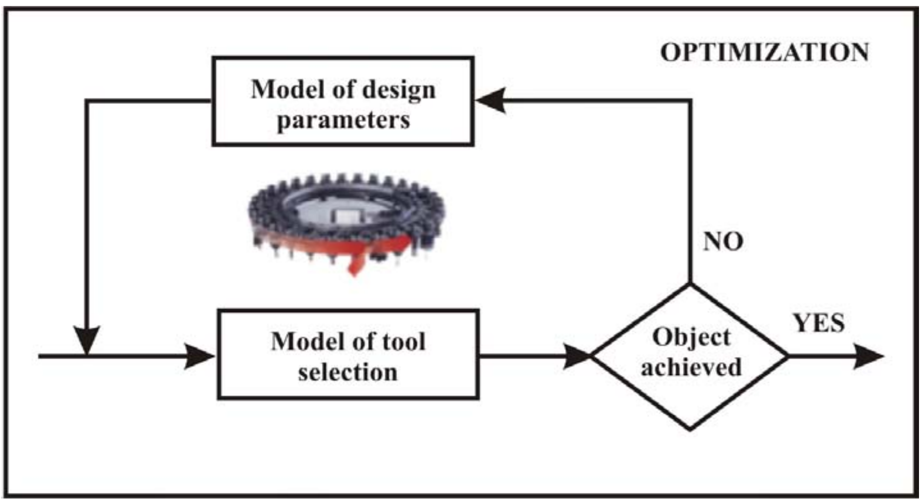

Fig. 5 Optimization process using intelligent tool selection

In each generation, improvements are made based on the selections of individuals according to the degree of adaptability within the field of the problem and their propagation between them, through operators borrowed from natural genetics. This process has a key role in the evolution of individual populations that are the most appropriate in their environments, the populations of which they are themselves created, the same as in natural adaptation.

A Genetic Algorithm [6] can include three operations as follows:

- selection,
- crossover and
- mutation.

The genetic algorithm selection is the process of determining the number of tests, the individuals selected for reproduction, and the number of individuals posterity will produce for our case of research. The basic operator during the production of new chromosomes in GAs is called the 'crossover'. Similarly to nature, the crossover produces new individuals who have some genetic similarities with both parents. The simplest form of crossover is single – point – crossover.

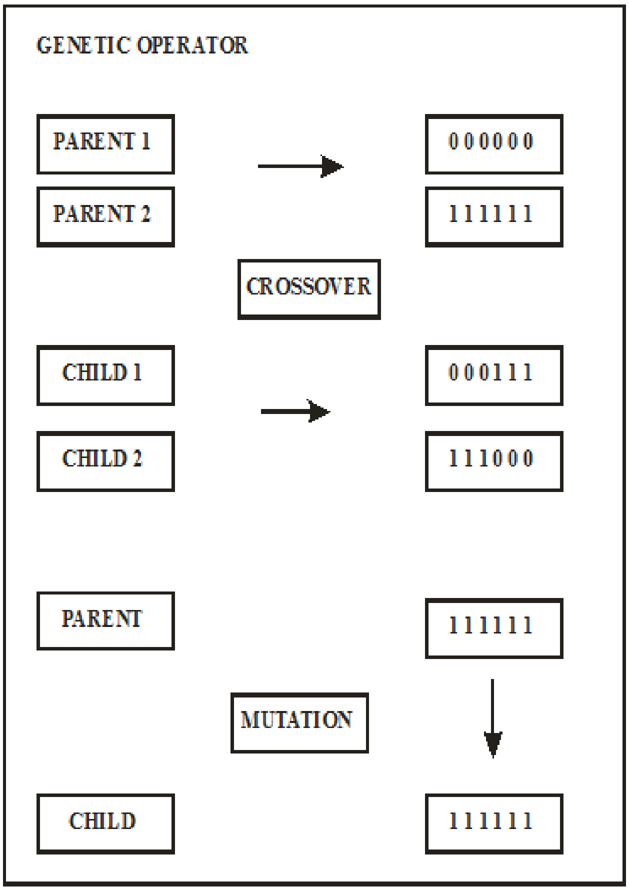

Fig. 6 Genetic operator (mutation and crossover)

In natural evolution, mutation is a random process when a gene is replaced with another gene, thus providing a new genetic structure. Therefore, it can be concluded that the methods for optimizing complex systems based on GAs are methods suitable for the optimization of parameters of tool path lengths.

Table 2 presents the results from the Genetic Algorithm after three runs. For each run of the Genetic Algorithm different results are obtained and these results will never be similar. As the global optimization method GA makes it possible to put two or more functions at the same time for some complexity problem and the best solution in the machining operation can be found.

Table 2 Optimal results achieved from Genetic Algorithm results for three independent runs

Machining parameters	*Initial values*	*Optimal value by GA*		
		Run 1	Run 2	Run 3
a [mm]	0.2	0.1	0.1	0.1
f [mm]	0.4	0.2	0.2	0.2
v [m/s]	2.8	2.305	2.3	2.302
Number of generation	-	52	51	51

After the optimizations for each of the three runs, the best fitness values based on the number of generations and the numbers of current iteration are obtained similarly.

Today, intelligent programming is defined as a function of artificial intelligence [8]. Basic knowledge, such as intelligent programming is a procedure carried out without human resources. Nowadays, intelligent programming plays an important role because of high market demands, and customers also require advanced technology for their needs. The presented work applies artificial intelligence such as Genetic Algorithms to finding the best solutions regarding tool selections for CNC machine tools. Genetic Algorithms are search algorithms based on the mechanism of natural selection and natural genetics. For our case, a general form of the genetic evolution method is presented for tool selection from magazine tool data. The program for solving equations regarding crucial time and tool selection is performed within the Matlab environment. The flowchart is presented in Fig. 7.

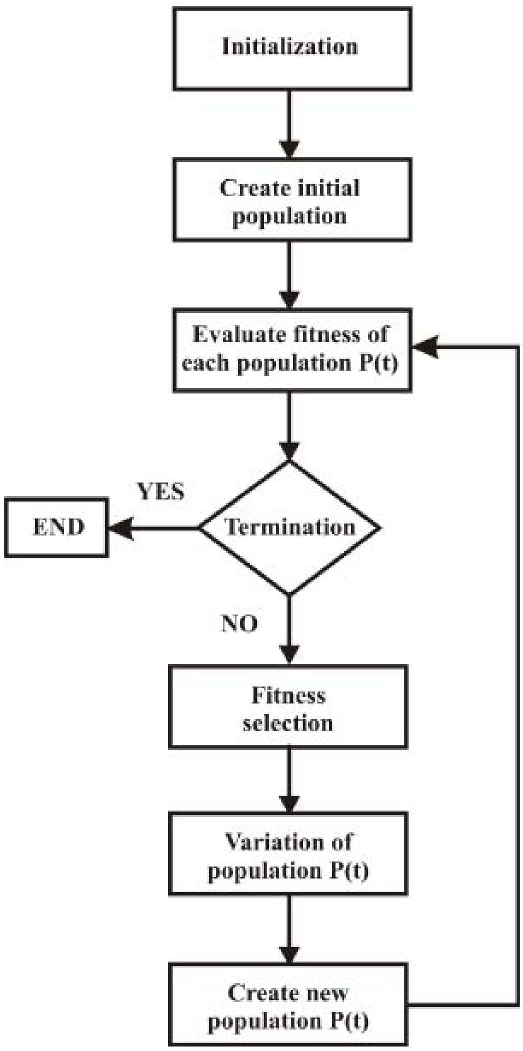

Fig. 7 Flowchart of the evaluation process using GAs for tool selection

The program starts by reading the machining parameters, tool selections, the number of input and output variables, initial conditions, and the number of iterations.

In order to implement the optimization of the crucial time and tool selection for lathe machining (Figure 7), three parameters are selected as optimization variables: feed rate (f), depth of cutting (a) and cutting speed (v). The lower and upper bound optimization of the parameters (constrains) are given as follows:

$$f_{\min} \leq f \leq f_{\max} \tag{8}$$

$$a_{\min} \leq a \leq a_{\max} \tag{9}$$

$$v_{\min} \leq v \leq v_{\max} \tag{10}$$

The optimization procedure for GA starts by reading the boundaries of variables and initializing the machining parameters: feed rate (*f*), depth of cut (*a*), and cutting speed (*v*) [13]. Furthermore, the main machining parameters are passed into the turning operation model for the rotational part in order to find more near optimal solutions during the crucial time. These values are substituted within a GA process to calculate the fitness function the objective function. The GA process is repeated and stops when the optimal solution is obtained.

5. Conclusions

In this paper, cutting tool selection was carried out by using a conventional CNC machine and by applying the method of an intelligent system for the geometry of a workpiece, such as turning and milling. The following conclusions have been reached.

The tool path length was presented based on an intelligent tool selection method as well as the complexities of the workpiece geometries. Also, the tool path for the rotational part is described by the application of the Matlab software (Fig. 4). In our case, two cutting tools were used for rough and final machining, the crucial time was carried out within the Matlab environment and described in relation to tool selection and machining parameters which had a direct influence on the optimizations of the machining processes.

GAs were utilized except for the tool selection method and at the same time the crucial times for rough and finished tool path of the turret CNC machine tools are optimized. The red line shows the tool path for rough machining, and the blue line shows the tool path for final machining (see above). The tool path length was carried out within the environment of the Matlab software. Fig. 5 presents the optimization process for the tool selection model. The analysis of the crucial time and tool selection was performed by estimations of the machining parameters and the tool paths for rough and final machining processes. The results are presented in Table 2 for each run for the lower and upper bounds, the number of iterations, as well as the initial values. The optimum results for our case have shown only one from three results for the first case, with 52 current iterations, and the best value based on the objective function value was obtained: 12.469034886859806.

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REFERENCES

[1] S.J. Chen, S. Hinduja, G. Barrow. Automatic tool selection for rough turning operations. International Journal of Machine Tools and Manufacture Volume 29, Issue 4, 1989, p. 535-553

[2] Zaryab Ahmad, Keyvan Rahmani, Roshan M. D'Souza. Applications of genetic algorithms in process planning: tool sequence selection for 2.5-axis pocket machining. Journal of Intelligent Manufacturing (2010) 21:461–470, DOI 10.1007/s10845-008-0201-6

[3] Z. Car ; B. Barisic; M. Ikonic. *GA based CNC turning center exploitation process parameters optimization.* Directory of Open Acess Journals Metallurgy (2009) 48(1) 47-50, ISSN 0543-5846

[4] Joze Balic, Franc Cus, Bostjan Vupatic. *Intelligent automatic cutting-tool selection for turning operations.* ICGST AIML – 11 Conference Dubai, UAE, 12-14 April (2011) p. 1-7.

[5] Ali Oral, M. Cemal Cakir. *Automated cutting tool selection and cutting tool sequence optimization for rotational parts.* Robotics and Computer-Integrated Manufacturing 20 (2004) p. 127–141.

[6] Joze Balic, Miha Kovacic, Bostjan Vaupotic. *Intelligent programming of CNC turning operations using genetic algorithm.* Journal of Intelligent Manufacturing (2006) 17:331–340

[7] S.H. Suh "Architecture and implementation of a shop-floor programming system for STEP-compliant CNC" Computer-Aided Design 35 (2003) 1069–1083,

[8] Wolfgang Ertel "Introduction to Artificial Intelligence" 2009, ISBN 978-0-85729-298-8

[9] Jones M. Tim, "Artificial Intelligence: An system approach" 2008, ISBN: 978-0-9778582-3-1, Publisher: David Pallai,

[10] Wang, Jun and Andrew Kusiak, "Computational intelligence in manufacturing handbook" 2000, ISBN 0-8493-0592-6

[11] ČUŠ, Franc, ŽUPERL, Uroš. Real-time cutting tool condition monitoring in milling. Journal of Stroj. vestn., Feb. 2011, vol. 57, no. 2, p. 142-150.

[12] T. Tamizharasan, N. Senthil Kumar. *Optimization of Cutting Insert Geometry Using DEFORM-3D: Numerical Simulation and Experimental Validation. International Journal of Simulation Modelling, Vol. 11, No. 2, 2012, p. 65-76.*

[13] KLANČNIK, Simon, BALIČ, Jože, ČUŠ, Franc. Intelligent prediction of milling strategy using neural networks. *Control Cybern.*, 2010, vol. 39, no. 1, p. 9-22.

[14] YAO Yunping et al. "Optimize CNC Milling Parameters On-line" International Conference on Measuring Technology and Mechatronics Automation China 2010.

[15] J. H. Holland. *Adaptation in Natural and Artificial Systems*. The University of Michigan Press, Ann Arbor, MI, 1975.

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