Software development for optimal selection of cutting parameters for productive CNC turning operation

Dr.S.Bharathi Raja
Principal
Indra Ganesan College of Engineering
Trichy-12, Tamil Nadu, India
drsbharathiraja@gmail.com

S.Abirami,G.Ranjani,G.Thangamari
Department of Mechanical Engineering
Indra Ganesan College of Engineering
Trichy-12, Tamil Nadu, India

ABSRACT

For the past more than one decade, mass productions are done with the aid of the Computer Numerical Control (CNC) machines. The CNC codes are programmed and feed in the CNC to get the automated machining process. The main parameters considered for machining in any turning operations are cutting speed, feed and depth of cut. The finished component depends not only on the dimensional accuracy and machining time but also on the surface finish. The present method of selection of machining parameters are carried out either by trial and error method in finding the suitable cutting parameters or from previous work experience of the process planner. Both the above said method is either tedious, time and cost consuming process or non-technical method of cutting parameters selection. There is a need to develop a simple solution to find the optimal machining parameters for required surface roughness in minimum possible machining time. In this work, based on the experimental investigations carried out [1] in Brass, Aluminium, Copper and Mild steel work material using Carbide tipped tool for turning operation, a dedicated software using Particle Swarm Optimization (PSO) was developed to suggest optimal cutting parameters for the desired surface roughness in minimized machining time. The suggested optimal cutting parameters are also verified by experimental investigations. The study reveals that software developed could suggest optimal cutting parameters to an accuracy of more than 90% with respect to actual experiments conducted.

Keywords: *CNC Turning, Cutting parameters,PSO, Surface Roughness, Machining time, Dedicated Software*

1. INTRODUCTION

Computer Numerical Control (CNC) machine plays vital role in the mass production. CNC machine are accurate, automated, and speed in nature. CNC machine are very costly compared to other machines and hence effective usage of machine are required. Selection of appropriate machining parameters is an important step in the process planning of machining operation. The present method of selection of machining parameters mainly depends either on previous work experience of process planner or selection thru machining data hand book. For the past two decades, research has been carried out using various traditional and non-traditional optimization methods to find the optimal cutting parameters. Experimental investigation, analysis and subsequent experimental verification have also been done to validate the new procedure. Various optimization techniques have been tested and found to be appropriate in giving near optimal cutting parameters. At this stage, there is a need to develop dedicated software which contains data base of ranges of machining parameters for various tools and work piece combination. Hence, in this present research, an attempt has been made to develop a dedicated software using PSO to suggest optimal cutting parameters for the required surface roughness in minimum possible machining time. This procedure was tested in four different work piece materials such as Brass, Aluminium, Copper and Mild Steel.

2. LITERATURE REVIEW

Bharathi Raja and Baskar [1] adopted PSO for optimize machining parameters to get desired surface roughness in minimum possible machining time. The author's claimed that average deviation and accuracy rate of predicted surface roughness to the actual surface roughness value is found to be 0.05 microns and 85% respectively. The average deviation and accuracy rate of the predicted machining time to the actual machining time is found to be 2 s and 96% respectively. Bharathi Raja and Baskar [2] examined SA, GA, and PSO in three different mathematical models such as single pass turning operation, multi-pass turning operation and grinding operation. The authors found that PSO outperformed the other optimization techniques in all the cases. Bharathi Raja and Baskar [3] investigated optimum machining parameters for turning operation using non-traditional optimization techniques such as SA, PSO, GA, Hybrid Algorithm (HA) and Memetic Algorithm (MA) and compared the results with traditional Nelder-Mead simplex (NMS) method. PSO has yielded best result among the non-traditional techniques. The result of PSO is 8% better than NMS method and 4.7% better than the least result obtained from non-traditional techniques.

Amiolemhen et al. [4] optimized machining parameters to determine minimum product cost of converting a cylindrical bar stock into a continuous finished profile involving seven machining operations such as facing, turning, centering, drilling, boring, chamfering and parting-off operation. Experimental results show that the proposed genetic algorithm is both effective and efficient. Ezugwa et al. [5] developed ANN model for the analysis and prediction of the relationship between cutting and process parameters during high speed turning of nickel-based Inconel 718 alloy. A very good agreement between predicted and experimental data was achieved and hence the model can be used for analysis and prediction of complex relationship between cutting conditions and process parameters.

Indrajit Mukherjee et al. [6] appraised the application potential of several modeling such as statistical regression technique, ANN, Response Surface Methodology (RSM) etc., and optimization techniques such as SA, GA and TS algorithm in metal cutting processes. Tansel et al. [7] proposed Genetically Optimized Neural Network System (GONNS) for the selection of optimal cutting condition from the experimental data, when analytical or empirical mathematical models were not available. The authors presented the relationships between the cutting conditions and machine related variables. Optimal operating conditions were also calculated to obtain the best possible compromise between roughness of machined surface and the duration. Raid Al-Aomar et al. [8] used GA to determine near optimal settings to both machining and production process parameters so that the overall per order production cost is minimized. The experimental results and the sensitivity analysis showed the robustness of the proposed GA. Finally, the effectiveness of GA was illustrated by outperforming the solution obtained from two-level and three-level full factorial designs. Yigit Karpat et al. [9] considered the non-linear relations between the machining parameters and the performance measures. These correlations were obtained using NN models through experimental data. PSO is used to handle the multi-objective optimization problem. The results indicate that the proposed PSO method is both effective and efficient and can be utilized in solving complex turning problems. Srinivas et al. [10] proposed a methodology for selecting optimum machining parameters in multi-pass turning using particle swarm intelligence. The methodology was illustrated with examples of bar turning and a component of continuous form. The author concluded that PSO could give stable optimal feasible solutions within a reasonable computational time.

Janez Kopac et al. [11] determined optimal cutting conditions for achieving desired surface roughness with a minimal number of experimental runs. The results revealed the fact that the majority of machining processes are performed outside the optimal cutting conditions, which has an essential impact on the process efficiency and the direct costs of machining

Benardos et al. [12] presented the various methodologies and practices employed for the prediction surface roughness. Each approach with its merits and demerits were outlined. The present and the future trends were also discussed. The approaches were discussed based on machining theory, experimental investigations, design of experiments and AI. The advantages of AI approaches were that they are more realistic and accurate. Moreover, particularities of equipment used and real machining phenomena are taken into consideration. In this study, surprisingly, a combined effort of both AI and analytical modeling to validate the theoretical models was not found in the literature.

Literature review reveals that most of the researchers have in implementation of traditional and non-traditional optimization techniques in finding the required machining objectives for enhancement. Moreover, for the past more than one decade, research has been focused much on various work materials and newer material for specific application. Almost all the researches have proved that the adopted techniques have performed far better than the existing method of selection of cutting parameters from the machining data hand book. Hence, it is a technical requirement to consolidate all the work done so far and to create a new database. Such attempt is made as a initiative in this research work in the form of dedicated software for four different work material with one tool material.

3. PROPOSED METHODOLOGY

The cutting parameters such as cutting speed, feed and depth of cut are identified as the parameters to be optimized. Although, there are other parameters which affect the machining time and desired surface finish, the selected parameters have more effect on the effect on the objective taken in this research work. Moreover, time and cost involved in changing the selected parameters during machining are negligibly small compared to other parameters such as nose radius, rake angle in tool nomenclature. Based on Bharathi Raja and Baskar [1], empirical model developed using pilot experiments are considered. Software has been developed using VISUAL BASIC in which PSO has been programmed to give optimized cutting parameters in minimum possible machining time for the desired surface roughness value given as input by the process planner. This is to eliminate the tedious process of selecting the appropriate cutting parameters from the machining data hand book for the specified tool and work piece combination. Various optimization techniques have been used so far to solve the machining problems. But, most of the results revealed that PSO have always yielded best result when compared to other optimization techniques. Hence, PSO has been utilized solve the machining problem in this research work.

3.1 Pilot Experiment

Pilot experiments are conducted by Bharathi Raja and Baskar [1] to study the effect of cutting parameters on machining time and surface roughness. CNC turning machine and surface roughness tester has been used for the experimentation. The diameter and length of the work piece was taken as 30 mm and 55 mm respectively. The specifications of the tool are given table 1.

Table 1: Specifications of the CNC turning tool

Tool material	: Insert type carbide
Specification	: CNMG 12-08-04
Length	: 12 mm
Thickness	: 08 mm
Nose radius	: 04 mm
Shape	: ISO diamond

Source: Bharathi Raja and Baskar [1]

The feasible range of cutting parameters for the considered tool and work piece are taken from ISCAR's complete machining solution for turning tools (a machining data hand book) and it is shown in table 2.

Table 2. Feasible range of cutting parameters for the proposed work materials.

Parameters .	Brass	Aluminium	Copper	Mild Steel
Cutting Speed (m/min)	50	50	50	50
	240	240	240	240
Feed (mm/rev)	0.062	0.062	0.010	0.010
	0.762	0.762	0.262	0.262
Depth of cut (mm)	1.5	1.5	0.3	0.3
	2.0	2.0	1.0	1.0

Source: ISCAR's complete machining solution

3.2 Development of Empirical relation

As per Bharathi Raja and Baskar [1], empirical model for the specific tool and work piece combination are derived based on the pilot experiments conducted using full factorial experimentation. Since mathematical relation is available for finding machining time, relation between surface roughness and cutting parameters are framed. In order to develop such relation, the effect of cutting parameters on the surface roughness has to be studied. ANOVA has been used for this purpose and the effects revealed are shown in equation (1) and equation (2). Based on the effect of cutting parameters on the surface roughness, it is found that the feed and depth of cut are directly proportional to the surface roughness and the cutting speed is inversely proportional to the surface roughness.

$(SR)_{turning}\ \alpha(f.d/v)$……………………………….…..……...(1)

Removing the proportionality, proportionality constants and coefficients are introduced in eq.(1) and the empirical relation between the cutting parameters and surface roughness is given in equation (2).

$(SR)_{turning} = k(v^{-a} f^{b} d^{c})$………..……………………….…….(2)

The value of constants and coefficients are found using the proposed PSO technique based on the effects of the cutting parameters on surface roughness observed from the pilot experiments. The equations formulated based on these approach is given below in eq.(3) to (6) for all the proposed four materials.

$SR_{Brass} = 2700(v^{-1.39}f^{0.79}d^{0.25})$…………………..…………..(3)

$SR_{Aluminium}=2750(v^{-1.40}f^{0.80}d^{0.25})$………………..………….(4)

$SR_{copper} =9550(v^{-1.52}f^{1.004}d^{0.25})$…………….…………….....(5)

$SR_{mild\ steel} =13000(v^{-1.52}f^{1.004}d^{0.25})$………..…………..……(6)

The standard equation for determining machining time is given in equation (7).

$T_m =(\Pi DL)/(1000vf)$………………..………………………(7)

where D=30mm,L=55mm

3.3 Particle Swarm Optimization

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr.Eberhart and Dr.Kennedy in 1995, inspired by social behavior of birds flocking. The intelligence of swarm is based on the principle of social and psychological behavior of the swarm. The optimization procedure is initialized with population of random solutions and searches for optima by updating generations. The potential solutions called particles fly through the problem space by following the current optimum particles. PSO is very easy to implement and there are few parameters to adjust. The algorithm can be explained based on the following scenario: a group of birds are randomly searching food in an area. There is only one piece of food in the area being searched. All the birds do not know where the food is. But they know far the food is in their search. So the best strategy to attain the food is to simply follow the bird, which is nearest to the food. In optimization problems, each bird in the search space is referred to as 'particle'. All the particles are evaluated by the fitness function to be optimized and have velocities for the particles. The particles fly through the problem space by following the current optimum particles. The problem is initialized with a group of random particles and then searches for optima by updating generations. In all the iterations, each particle is updated by following two ‘best’ values. The best solutions achieved so far among the particle is called as ‘particle best’ termed as ‘pbest’ and the best solution obtained so far in the population is called as ‘global best’ termed as ‘gbest’. A particle takes the entire particle toward its pbest and gbest locations. After finding the two best values, the particles are updated with its velocity and positions using eqs. (8) and (9)

V[ ]=c_1 rand( ) (pbest[ ] - present[ ]) + c_2 rand( ) (gbest[ ] - present[ ])……………………………………………..…(8)

P[ ]=V[ ] + present[ ]…………………………………….……(9)

V[] is the particle velocity, present [ ] is the current particle, pbest and gbest are defined as stated before, rand() is the random number between 0 and 1. c_1,c_2 are learning factors usually varies from 1 to 4 and P[ ] is new particle position.

Compared to other optimization techniques, the information sharing mechanism in PSO is significantly different. Only ‘gbest’ gives out information to others, which is one-way information sharing mechanism. The algorithm attempts to find only the best solution and hence all the particles tend to converge to the best solution quickly in most cases. The advantages of using PSO are that it takes real numbers as particles and there are few parameters to adjust. The searching is a repeat process and the stop criteria are that the maximum iteration is reached or the minimum error condition is satisfied. The various parameters in PSO are number of particles, dimension of particles, and range of particles, learning factor, stop condition and global vs local version.

3.3.1 Algorithm

The various steps involved in the procedure of PSO for solving any optimization problem is given bewlow:

Step 1: Initialize a population of n particles randomly

Step 2: Calculate fitness value for each particle. If the fitness value is better than the best fitness value (pbest) in history, set current value as the new pbest.

Step 3: Choose particle with the best fitness value of all the particles considered so far as the gbest.

Step 4: For each particle; calculate particle velocity and position according to eqs (8)and (9).

Step5: Particle velocities on each dimension are clamped to a maximum velocity v_{max}. If the sum of acceleration would cause the velocity on that dimension to exceed v_{max} (specified by the user), the velocity on the dimension is limited to $v_{max.}$

Step 6: Terminate if maximum number of iterations is reached. Else, go to step 2.

Step 7: End.

3.3.2 Parameters of PSO

The parameters of PSO technique used in the proposed methodology are given below.

Number of iteration performed	: 1000
Population	: 100
Learning factor c_1	: 2
Learning factor c_2	: 2

3.3.3 Numerical elucidation of PSO

Cutting parameters are optimized using PSO technique and the coding was done using MINI ART SYSTEM programming software. 1000 iterations with 100 populations were used to run the program. The program is executed to get optimized cutting parameters for minimizing machining time subject to the required surface roughness values obtained from pilot experiments. The computational time for execution of single run in a core 2 Duo processer computer are observed to be less than 5 seconds in an average. The procedure of PSO is explained below with respect to the first particle in the first iteration. Similarly, the remaining 99 particles are executed by the same procedure. This constitutes iteration 1. The remaining 999 iterations are executed in the same manner.

3.3.4 Calculation of optimum machining parameters

Cutting speed is calculated randomly within the limits using equation (10).

$v = v_{min} + (v_{max} - v_{min})$ rand ( )…………….……………….(10)

Feed is also calculated randomly within the limits using equation (11).

$f = f_{min} + (f_{max} - f_{min})$ rand ( )……….………………….…..(11)

similarly depth of cut is also calculated randomly within the limits using equation (12)

$d = d_{min} + (d_{max} – d_{min})$ rand ( )………………………….(12)

Equations (10) – (12) act as the constraints and hence these equations have to be satisfied before proceeding to the nect step. The cutting parameters obtained from the constraint equations are then tested in equation (13), which checks the attainment of the desired surface roughness value. If the tested optimal cutting parameters does not able to attain the desired surface roughness, then the entire procedure have to be repeated with other possible optimal cutting parameters based on new random numbers.

$K (v^{-a} f^b d^c) = SR_{desired}$..(13)

After satisfying equation (13), the optimized cutting parameters are substituted in machining time equation (7). If the machining time value is either same or less than the previous iteration, then both surface roughness and machining time will accepted, otherwise, the above steps should be repeated with new random numbers.

3.3.5 Calculation of pbest value

The required surface roughness acquired in minimum machining time for each initial solution for the present iteration is considered as pbest value. This is the best value of the particular iteration only.

3.3.6 Calculation of gbest value

The required surface roughness acquired in minimum machining time obtained from the entire iterations executed so far is considered as the gbest value. This is considered as the best value from all the iterations executed so far.

4. RESULTS AND DISCUSSION

The coding for optimization was written in MINI ART SYSTEM for four different work piece materials such as Brass, Aluminium, Copper and Mild Steel. The tool material is insert type carbide tool which is common for all the work materials. The developed programs were merged in a user friendly interactive dedicated software using VISUAL BASIC. The developed software acts as a database for the considered four work materials and the tool. It eliminates the tedious process of referring a machining data hand book in which exhaustive search has to be carried out in find the suitable cutting parameters for the specific tool and work material. The machining data hand book is designed to give a range of cutting parameters, which is not specific or which could not give specific cutting parameters. But, the developed software in this research work could able to display the optimal cutting parameters for the specific surface roughness that too in minimum possible machining time. Figure 1 shows the front page of the developed software.

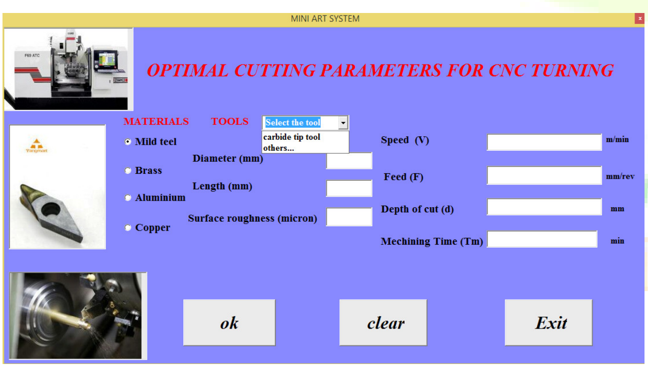

Figure 1: User friendly dedicated software front page.

The process planner has to select the tool and work material available in the database of the developed software. The required profile of the work piece is also to be entered in the appropriate tab and finally, the required surface roughness has to be entered. The software immediately starts functions and displays the optimal cutting parameters and expected machining time on the screen.

The cutting parameters suggested by the developed dedicated software for the desired surface roughness in minimum possible machining time is given in table 3. Surface roughness to be given as input was selected randomly at various levels and given as input to the developed software apart from dimensions of the work piece to be machined. The minimized machining time and its corresponding cutting parameters will be displayed on the front page of the developed software.

Table 3: Optimized parameters evolved from the developed software for the desired surface roughness

S.No.	SR μm	v m/min	f mm/rev	d mm	t_m sec
1	2.15	158.264	0.140	0.430	40
2	2.30	192.083	0.160	0.663	26
3	0.70	169.008	0.120	0.405	50
4	3.22	141.913	0.150	0.947	48
5	3.42	141.519	0.084	0.792	72
6	3.10	183.422	0.064	0.533	93
7	0.24	183.559	0.110	0.912	68
8	3.50	149.570	0.140	0.313	50
9	0.30	216.909	0.050	0.904	85
10	2.31	125.518	0.110	0.411	74

The CNC turning machine used for experimental verification of the predicted cutting parameters by the developed software is shown in figure 2.

Figure 2: CNC turning machine used for the experiments

The surface roughness tester used for measuring the machined surface in the verification of the predicted surface roughness is shown in figure 3.

Figure 3: Surface roughness tester used in the experiments

Then the suggested optimal cutting parameters and its machining time and surface roughness are verified by conducting experiments, which are given in table 4. Surface roughness on a specimen was taken at three different places to ensure repeatability and the average is considered. Calibration is done before every experiment to ensure accuracy.

Table 4: Machining time and surface roughness obtained from experiment for the given optimized cutting parameters.

S.No.	v m/min	f mm/rev	d mm	t_m sec	SR µm
1	158.264	0.140	0.430	46	2.34
2	192.083	0.160	0.663	31	2.35
3	169.008	0.120	0.405	55	0.84
4	141.913	0.150	0.947	39	3.42
5	141.519	0.084	0.792	54	3.58
6	183.422	0.064	0.533	97	3.39
7	183.559	0.110	0.912	98	0.32
8	149.570	0.140	0.313	56	3.84
9	216.909	0.050	0.904	55	0.42
10	125.518	0.110	0.411	80	2.54

It was observed that the predicted cutting parameters for achieving the desired surface roughness in minimum machining time are found to be very close to the experimental values. Figure 4 depicts the graphical representation of predicted machining time and the experimental machining time. Figure 5 depicts the graphical representation of the predicted surface roughness and the experimental surface roughness.

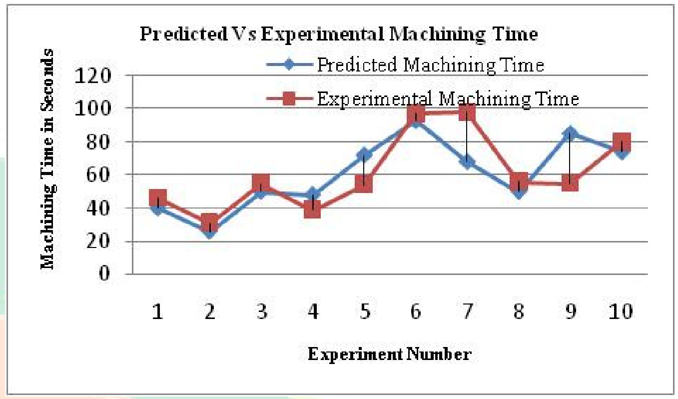

Figure 4: Predicted Vs Experimental machining time

It was evident from the figure 4 that the predicted machining time was found to be very close to the experimental machining time. The maximum deviation was observed to be 30 seconds and minimum 5 seconds, the average deviation bring 11.9 seconds (3.37%)

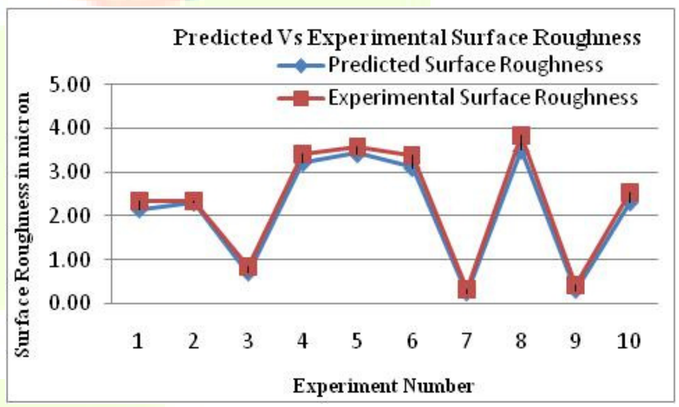

Figure 5: Predicted Vs Experimental Surface Roughness

It was evident from the figure 5 that the predicted surface roughness was found to be very close to the experimental surface roughness. The maximum deviation was observed to be 0.34 micron and minimum 0.05 micron, the average deviation being 0.18 micron 14.43%)

5. CONCLUSION

In this research work, a new approach in selecting cutting parameters has been initiated in the manufacturing environment. The followings are the summary of the results of the proposed methodology in finding optimal cutting parameters for achieving the desired surface roughness in minimum possible machining time:

1. The proposed approach has eliminated the tedious process of selecting cutting parameters from the machining data hand book.

2. The dedicated software acts as the data base for the specific tool and work material combination.

3. Average deviation with respect to predicted and experimental machining time was observed to be 11.9 seconds (3.37 %).

4. Average deviation with respect to predicted and experimental surface roughness was observed to be 0.18 micron (14.43%).

5. The time taken to get the optimal cutting parameters for the desired surface roughness is less than 5 seconds from the software. This is possible within the available tool and work material in the software database.

6. The time involved in getting the optimal cutting parameters within the available tool and work material database is legibly small when compared to severe search from the hand book.

7. The cost involved in installing the dedicated software is completely nothing. Moreover, cost does not involve while changing / feeding various cutting parameters in the CNC machine.

8. The developed software is user friendly and hence it can be very well installed in the computer interfaced with the CNC machine.

9. This approach shall be implemented in other machining operations such as milling, grinding etc.

10. There is a large scope for strengthening the developed database software by following the proposed methodology.

Scope for future work

1. The developed software can be extended to other work and tool materials.

2. Recently developed new materials may also be included in the database of the proposed software.

3. More number of input parameters for optimization may be added to be more realistic in the objectives.

REFERENCES

[1] S.Bharathi Raja and N Baskar, "Particle Swarm Optimization technique for determining optimal machining parameters of different work piece materials in turning operation", Int J Adv Manuf Technol, vol.54, pp.445-463, 2011.

[2] S Bharathi Raja and N Baskar, "Investigation of optimal machining parameters for turning operations using intelligent techniques", Int J Mach Machinable Mater, vol.8, pp.146-166,2010.

[3] S.Bharathi Raja and N Baskar, "Optimization techniques for machining operations: A retrospective research based on various mathematical models", Int J Adv Manuf Technol, 48, pp.1075-1090, 2009.

[4] Amiolemhen PE, Ibhadide AOA, "Application of genetic algorithms – determination of the optimal machining parameters in the conversion of a cylindrical bar stock into a continuous finished profile", Int J Mach Tool Manuf, vol.44, pp.1403-1412, 2004.

[5] Ezugwa EO, Fadare DA, Bonney J, Silva RB, Sales WF, "Modeling the correlation between cutting and process parameters in high speed machining of Inconnel 718 alloy using artificial neural network", Int J Mach Tool Manuf, vol.45, pp1375-1385, 2005.

[6] Indrajit Mukherjee, Ray PK, "A review of optimization techniques in metal cutting processes", J Comp Ind Engg, vol.50, pp15-34, 2006.

[7] Tansel IN, Ozcelik B, Bao WY, Chen P, Rincon D, Yang SY, Yenilmez, "A Selection of optimal cutting conditions by using GONNS". Int J Mach Tool Manuf, vol46, pp.26-35, 2006.

[8] Raid Al-Aomar, Ala'a Al-Okaily, "A GA based parameter design for single machine turning process with high volume production. Comp Ind Engg, vol.50, pp.317-337, 2006

[9] Yigit Karpat, Tugrul Ozel, "Multi-objective optimization for turning processes using Neural network modeling and dynamic neighborhood Particle Swarm Optimization", Int J Adv Manuf Technol, vol.35, pp.234-247, 2007.

[10] Srinivas J, Giri R, Yang SH, "Optimization of multi-pass turning using Particle Swarm Intelligence", Int J Adv Manuf Technol, vol.40, pp.56-66, 2009.

[11] Janez Kopac, Marko Bahor, Mirko Sokovic, "Optimal machining parameters for achieving the desired surface roughness in fine turning of cold pre-formed steel workpieces", Int J Mach Tool Manuf, vol.42, pp.707-716, 2002.

[12] Benardos PG, Vosniakos GC, "Prediction of surface roughness in CNC face milling using neural networks and Taguchi's design of experiments", Robotics and Comp Int Manuf, vol.18, pp.343-354,2002.

