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Optimization of Cutting Parameters Using Genetic Algorithm and Particle Swarm Optimization

G. Bala Subramanyam[1], P. Punna Rao[2]

M.Tech (Student) Mechanical Engineering, NIMRA College of Engineering & technology

M.Tech Asst Professor of Mechanical Engineering Department, NIMRA College of Engineering & Technology, Jupudi, Vijayawada. A.P

Abstract: *In machining operations, achieving desired surface quality features of the machined product, is really a challenging job. Because, these quality features are highly correlated and are expected to be influenced directly or indirectly by the direct effect of process parameters or their interactive effects (i.e. on process environment). However, the extents of significant influence of the process parameters are different for different responses. Therefore, optimization of surface roughness is a multi-factor, multi-objective optimization problem. Therefore, to solve such a multi-objective optimization problem, it is felt necessary to identify the optimal parametric combination, following which all objectives could be optimized simultaneously. In this context, it is essential to convert all the objective functions into an equivalent single objective function or overall representative function to meet desired multi-quality features of the machined surface. The required multi-quality features may or may not be conflicting in nature. The representative single objective function, thus calculated, would be optimized finally. In the present work, Design of Experiment (DOE) with Design of Expect software, Mini Tab & optimized using genetic algorithm by MAT Lab and Particle Swarm Optimization (PSO) by "C" program in straight turning operation. Collected data related to surface roughness have been utilized for optimization. Due to complexity of this machining optimization problem, a genetic algorithm (GA) and Particle Swarm Optimization (PSO) are applied to resolve the problem and the results obtained from GA and PSO are compared.*

Keywords: *Turning Operation; Surface Roughness; Genetic Algorithm; Particle Swarm Optimization.*

I. Introduction

Surface roughness has received serious attention for many years. It has formulated an important design feature in many situations such as parts subject to fatigue loads, precision fits, fastener holes, and aesthetic requirements. In addition to tolerances, surface roughness imposes one of the most critical constraints for the selection of machines and cutting parameters in process planning. A considerable number of studies have investigated the general effects of the speed, feed, and depth of cut on the surface roughness.

To improve the efficiency of these turning processes, it is necessary to have a complete process understanding and model. To this end, a great deal of research has been performed in order to quantify the effect of various hard turning process parameters to surface quality. These factors can be divided into a) setup variables, b) tool variables, and c) work piece variables. In order to gain a greater understanding of the turning process it is necessary to understand the impact of the each of the variables, but also the interactions between them. It is impossible to find all the variables that impact surface roughness in turning operations. In addition, it is costly and time consuming to discern the effect of the every variable on the output. In order to simplify the problem, one needs to eliminate or select specific variables that correspond to practical applications.

II. Literature Survey

Parametric Analysis and Optimization of Cutting Parameters for Turning Operations based on Taguchi Method by **Dr. S.S.Mahapatra Amar Patnaik Prabina Ku. Patnaik (1) in** this paper they have conducted experiment work and done on Genetic Algorithm to optimization the experimental values. On-line optimization of the turning using an inverse process neurocontroller, Transactions of ASME, Journal of Manufacturing Science and Engineering by **R. Azouzi, M. Guillot,(2)** Process modeling and optimization are the two important issues in manufacturing products. The manufacturing processes are characterized by a multiplicity of dynamically interacting process variables

Surface roughness prediction models for fine turning; International Journal of Production Research by **A. Mital, M. Mehta (3)** a greater attention is given to accuracy and surface roughness of product by the industry these days. Surface finish has been one of the most important considerations in determining the machinability of materials. Surface roughness and dimensional accuracy are the important factors required to predict machining performances of any machining operations.

Present situation and future trends in modeling of machining operations. Progress Report of the CIRP working group on 'Modeling of machining operations by **C.A. Van Luttervelt, T.H.C. Childs, I.S. Jawahir, F. Klocke, P.K.Venuvinod.(4)** The predictive modeling of machining operations requires detailed prediction of the boundary conditions for stable machining. The number of surface roughness prediction models available in literature is very limited. Most surface roughness prediction models are empirical and are generally based on experiments in the laboratory. In addition it is very difficult in practice, to keep all factors under control as required to obtain reproducible results. Generally these models have a complex relationship between surface roughness and operational parameters, work materials and chip-breaker types.

Multi machining output—multi independent variable turning research by response surface methodology, International Journal of Production Research by **K.Taraman(5)** used Response Surface Methodology (RSM) for predicting surface roughness of different materials. A family of mathematical models for tool life, surface roughness and cutting forces were developed in terms of cutting speed, feed, and depth of cut. Comparison of a full factorial experiment to fractional and taguchi designs in a lathe dry turning operation by **Youssef a. Youssef, yves beauchamp** and **marc Thomas(6)** F~cole de technologie superieure 4750, ave henri-julien, montr6al, Canada . This paper presents a comparison of three different Experimental designs aimed at studying the effects of cutting Parameters variations on surface finish. The results revealed That the effects obtained by analyzing both fractional and Taguchi designs (16 trials each) were comparable to the main Effects and tow-level interactions obtained by the full factorial Design (288 trials). Thus, we conclude that screening designs Appear to be reliable and more economical since they permit to Reduce by a factor 18 the amount of time and effort required to Conduct the experimental design without losing valuable Information.

Investigation Of Cutting Parameter Effects On Surface Roughness In Lathe* Boring Operation By Use Of A Full Factorial Design **Yves Beauchamp,ext (7)** The main objective of this study is to investigate cutting parameter effects of surface roughness in a lathe dry boring operation. A full factorial design was used to evaluate the effect of six (6) independent variables (cutting speed, feed rate, depth of cut, tool nose radius, tool length and type of boring bar) and their corresponding two-level interactions. In this experiment, the dependant variable was the resulting first cut surface roughness (Ra).

Determination of optimal cutting conditions using design of experiments and optimization Techniques **M. S. CHUAT (8)** In process planning or NC part programming, optimal cutting conditions are to be determined using reliable mathematical models representing the machining conditions of a particular work-tool combination. The development of such mathematical models requires detailed planning and proper analysis of experiments. In this paper, the mathematical models for TiN-coated carbide tools and RSchling T4 mediumcarbon steel were developed based on the design and analysis of machining experiments. The models developed were then used in the formulation of objective and constraint functions for the optimization of a multipass turning operation with such work-tool combinations

III. Problem Description

To find the optimum machining parameters in order to get the minimum surface roughness. Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) are used to do this and the results are compared.

We have taken 14 samples of turning operation in finishing cut the values of the speed, feed and depth of cut and their respective surface roughness. The value obtained in this by varying three parameter are taken in design of expect V-8 software to obtain an equation. In the response surface methodology the linear and second order polynomials were fitted to the experimental data for obtaining regression equations.

And then using Particle Swarm Optimization (PSO) algorithm we can obtain the optimization value by using C-program and similarly optimized using genetic algorithm by MAT Lab

In this paper the optimal machining parameters for continuous profile machining are determined with respect to the minimum production time, subject to a set of practical constraints, cutting force, power and dimensional accuracy and surface finish. Due to complexity of this machining optimization problem, a genetic algorithm (GA) and Particle Swarm Optimization (PSO) are applied to resolve the problem and the results obtained from GA and PSO are compared.

3.1Objective Function:

The full development of machining process planning is based on optimization of the economic criteria subject to technical and managerial constraints. The economic criteria are the objectives of machining operations in terms of quality.

The objectives considered in this paper are surface roughness to be minimized

IV. Experimental Part

The present study has been done through the following plan of experiment.

a) Checking and preparing the Centre Lathe ready for performing the machining operation.
b) Cutting ***S45C*** bars by power saw and performing initial turning operation in Lathe to get desired dimension (of diameter 59 mm and length 100mm) of the work pieces.
c) Performing straight turning operation on specimens in various cutting environments involving various combinations of process control parameters like: spindle speed, feed and depth of cut.
d) Measuring surface roughness and surface profile with the help of a portable stylus-type profilometer, ***Talysurf*** (Taylor Hobson, Surtronic 3+, UK)

Experimental Details

Turning is one of the most common of metal cutting operations. In turning, a work piece is rotated about its axis as single-point cutting tools are fed into it, shearing away unwanted material and creating the desired part. Turning can occur on both external and internal surfaces to produce an axially-symmetrical contoured part.

Parts ranging from pocket watch components to large diameter marine propeller shafts can be turned on a lathe. The capacity of a lathe is expressed in two dimensions. The maximum part diameter, or "swing," and the maximum part length, or "distance between centers."

The general-purpose engine lathe is the most basic turning machine tool. As with all lathes, the two basic requirements for turning are a means of holding the work while it rotates and a means of holding cutting tools and moving them to the work. The work may be held on one or by both its ends. Holding the work by one end involves gripping the work in one of several types of chucks or collets. Chucks are mounted on the spindle nose of the lathe, while collets usually seat in the spindle. The spindle is mounted in the lathe's "headstock," which contains the motor and gear train that makes rotation possible. Directly across from the headstock on the lathe is the "tailstock." The tailstock can hold the work by either alive or dead center. Work that is held at both ends is said to be "between centers." Additionally, longer work pieces may have a "steady rest" mounted between the headstock and tailstock to support the work. Typically work pieces are cylindrical, but square and odd shaped stock can also be turned using special chucks or fixtures. Lathe cutting tools brought to the work may move in one or more directions. Tool movement on the engine lathe is accomplished using a combination of the lathe's "carriage", "cross slide", and "compound rest".

The carriage travels along the machine’s bed ways, parallel to the work piece axis. This axis is known as the "Z" axis. Motion perpendicular to the work is called the "X" axis. On an engine lathe this motion is provided by the cross slide mounted on the carriage.

Atop the cross slide is the "compound rest," which can be rotated to any angle and secured. The compound rest also holds the "tool post," where tools are mounted. Tools may also be mounted in the tailstock for end-working operations.

Cutting Tool

Tungsten carbide with the grade of P-10 Tungsten carbide also called cemented carbide, hard metal. There are 2 compounds of tungsten and carbon, WC and tungsten semi carbide.

Work piece Material

S45C OR Equivalent Alloy (1045)
COMPOSITION:

METALS	COMPOSITION	
	MIN	MAX
Carbon	0.42	0.48
Silicon	0.15	0.35
Manganese	0.60	0.90
Phosphorus	max0.03	
Sulphur	max0.035	
IRON	REMAINING	

Typical Applications:

Axles, bolts, connecting rods, studs, rams, pins, rolls, spindles, ratchets, crankshafts, torsion bars, sockets, worms, light gears, guide rods etc.

The working ranges of the parameters for subsequent design of experiment, based on Taguchi’s L27 Orthogonal Array (OA) design have been selected. In the present experimental study, spindle speed, feed rate and depth of cut have been considered as process variables. The process variables with their units (and notations) are listed in Table 4.1

Table 4.1: Process variables and their limits

Variables		Values of different levels		
Designation	**Description**	**Low (-1)**	**Medium (0)**	**High (+1)**
D	Depth of cut (mm)	**0.6**	**1.00**	**1.60**
F	Feed rate (mm/rev)	**.08**	**0.2**	**0.32**
V	Cutting speed (m/min)	**135**	**210**	**285**

Measuring Surface Roughness:-

Roughness measurement has been done using a portable stylus-type profilometer, *Talysurf* (Taylor Hobson, Surtronic 3+, UK).

Experiments have been carried out using Taguchi's L27 Orthogonal Array (OA) experimental design which consists of 27 combinations of spindle speed, longitudinal feed rate and depth of cut. According to the design catalogue prepared by Taguchi, L 27 Orthogonal Array design of experiment has been found suitable in the present work. It considers three process parameters (without interaction) to be varied in three discrete levels. The experimental design has been shown in Table 4 (all factors are in coded form). The coded number for variables used in Table 4.3 and 4.4 are obtained from the following transformation equations:

By obtain Taguchi's L27 Orthogonal Array the experiment have be conducted and the value of the particular feed, speed and depth of cut are given below

Std	Cutting speed	Feed rate	Depth of cut	Surface Roughness
	m/min	mm/rev	mm	µm
1	135	.08	0.6	2.086
2	135	.08	1	2.338
3	135	.08	1.6	2.522
4	135	.2	0.6	4.326
5	135	.2	1	4.714
6	135	.2	1.6	5.044
7	135	.32	0.6	6.887
8	135	.32	1	7.2362
9	135	.32	1.6	7.788
10	210	.08	0.6	3.414
11	210	.08	1	3.618
12	210	.08	1.6	3.773
13	210	.2	0.6	5.966
14	210	.2	1	6.1983
15	210	.2	1.6	6.363
16	210	.32	0.6	8.041
17	210	.32	1	8.197
18	210	.32	1.6	8.303
19	285	.08	0.6	4.391
20	285	.08	1	4.521
21	285	.08	1.6	4.608
22	285	.2	0.6	6.868
23	285	.2	1	6.994
24	285	.2	1.6	7.071
25	285	.32	0.6	8.536
26	285	.32	1	8.304
27	285	.32	1.6	8.653

V. Experimental Results And Analysis

The experimental results are presented in Table given below For the purpose of developing the mathematical model; both the data for the machining responses and factors were logarithmically transformed. Using these sets of data, the parameters for the mathematical models were determined using the multiple regression method and the significance of the models and the parameters were then analyses using analysis of variance. In this work, a commercially available statistical software package DOE was used for the computation of regression and statistical analysis of the constants and parameters. The procedure PROC REG from this package was used to compute values of the mathematical models and to carry out the analysis of variance for the models developed. In the following sections, the significance of each model developed will be discussed. The experimental value were obtain form the experiment is given the following table 5.1 and 5.2 and by using above software's the mathematical equation is obtain in term of speed, feed and depth of cut for the surface roughness.

Using Design-Expect Software
SURFACE ROUGHNESS (Ra)

TABLE 5.1 ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	DoF	Mean	F Value	p-value Prob > F	
Model	110.4894389	9	12.2766	561.2594	< 0.0001	**Significant**
A-A	15.68472238	1	15.68472	717.0711	< 0.0001	
B-B	18.69230265	1	18.6923	854.571	< 0.0001	
C-C	0.724005556	1	0.724006	33.09994	< 0.0001	
AB	0.889549653	1	0.88955	40.66826	< 0.0001	
AC	0.182698201	1	0.182698	8.352561	0.0102	
BC	4.18E-05	1	4.18E-05	0.001911	0.9656	
A^2	0.437292007	1	0.437292	19.99203	0.0003	
B^2	73.37755104	1	73.37755	3354.661	< 0.0001	
C^2	0.001906597	1	0.001907	0.087165	0.7714	
Residual	0.37184638	17	0.021873			
Cor Total	110.8612852	26				

TABLE 5.2 Analysis of variance (ANOVA) for Surface Roughness

Actor	**Coefficient Estimate**	**Df**	**Standard Error**	**95% CI Low**	**95% CI High**	**VIF**
Intercept	**3.6806**	**1**	**0.077**	**3.518111**	**3.84**	
A-A	**0.9365**	**1**	**0.035**	**0.862751**	**1.01**	**1.007**
B-B	**-1.0224**	**1**	**0.035**	**-1.09618**	**-0.9**	**1.007**
C-C	**0.2006**	**1**	**0.035**	**0.127008**	**0.27**	**1.013**
AB	**0.2723**	**1**	**0.043**	**0.18219**	**0.36**	**1**
AC	**-0.1226**	**1**	**0.042**	**-0.21206**	**-0**	**1.007**
BC	**-0.0019**	**1**	**0.042**	**-0.09134**	**0.09**	**1.007**
A^2	**-0.27**	**1**	**0.06**	**-0.39735**	**-0.1**	**1**
B^2	**3.4971**	**1**	**0.06**	**3.369696**	**3.62**	**1**
C^2	**-0.0187**	**1**	**0.063**	**-0.15227**	**0.11**	**1.013**

Final Equation in Terms of Coded Factors:

$$Ra =+ 6.184 + 0.9711* A + 2.2593* B + 0.1811* C- 0.1991* A * B - 0.0989 * A * C - 0.0018* B * C - 0.2677 * A^2 - 0.21277 * B^2- 0.06667* C^2$$

Final Equation in Terms of Actual Factors:

$$Ra = -5.257 + 0.0402 * A + 29.4195 * B + 1.50896 * C - 0.0221* A * B - 0.0016637 * A * C - 0.0311 * B * C\ 4.8 e^{-5} * A^2 - 14.776 * B^2 - 0.266666* C^2$$

VI. Optimization Of Cutting Parameters

6.1 Particle Swarm Optimization (PSO)

In recent years, the collective behavior of large numbers of moving cooperative agents, frequently called particles, has proven to be useful in the fields of optimization and control. The collection of these particles is called a swarm and its application is referred to as swarm intelligence. The power of swarm intelligence is that simple behavior on the local level can result in useful, often more complex, and behavior on the global level. Even if the individual agents are too simple for the label 'intelligent', the swarm often does manifest intelligent behavior. The global behavior of the swarm is difficult to predict based on the local dynamics of the particles.

6.2 Genetic Algorithm

Machining optimization problem requires a robust search method (Robustness means numerical stability and ability to find a solution for a wide range of algorithmic parameters), which runs well in complex situations. The genetic algorithm **(GA)** approach has been selected firstly because their behavior is robust and so far efficient and secondly more and more attention is being is drawn to GA in a variety of disciplines. Evolution program started in the sixties when a group of biologists used digital computers to simulate genetic systems

6.3 Procedure for Genetic Algorithm

1. The sample values given below are taken and these values are used to train the network.
2. Then the network is exported to the Matlab workspace and this network is selected and tested by using the same values as input and the layers and numbers of neurons per layer are varied in order to get the best network.
3. Then this network works as Regression equation and it is used in the genetic algorithm program in order to get the optimum result.
4. Here we are using minimization problem and the objective is minimized and the optimum parameters to get the minimized objective is found

Procedure of Single Objective Optimization

1. At first random strings are generated such that the string is divided into the inputs such as speed, feed and depth of cut.
2. Then the strings are sent into a fitness function, we know that genetic algorithm is based on survival of the fittest.
3. Then the minimum fitness function is generated, generally GA is used for maximization problems, so the minimum fitness function is converted in maximum fitness function
4. Then find the cumulative fitness function
5. By using the cumulative fitness function find the normalized fitness function.
6. By using the normalized fitness function find the minimum
7. Then give string numbers to each string.
8. Then generate a matpool based on the string numbers.
9. Then apply the genetic operators on the matpool such as crossover mutation etc so that a new population is generated. This population is used as an input for the next generation.
10. Then find the optimum values for finding the minimum fitness function

VII. Conclusions

Genetic Algorithm

A neural network is created based on experimental values is used instead of mathematical models and optimized machining parameters are found using Genetic algorithm.

By training the network using single objective function and using genetic algorithm optimum speed, feed and depth of cut are evaluated and the corresponding values of objective functions for corresponding speed feed and depth of cut are found and the results are as follows.

1. By optimization of surface Roughness

Optimum speed = 145.405 m/min
Optimum feed = 0.0876 mm/rev
Optimum depth = 0.6057 mm
Minimized surface roughness =2.494 µm

Particle Swarm Optimization

By obtained equation form the design of expect software and written particle swarm optimization in c-language the program obtain the corresponding value of objective function for corresponding speed feed and depth of cut are found and the results are as follows.

2. By optimization of surface Roughness

Optimum speed = 145m/min
Optimum feed = 0 .08 mm/rev
Optimum depth = 0.6 mm
Minimized surface roughness =3.199 µm

Based on the conducted experiments and accomplished analysis, the following conclusions can be made

1. The speed and feed rate are the most significant factors in surface roughness model.
2. All types of lathe machines have been used to produce continuous finished profiles. A continuous finished profile has many types of operations such as turning. To model the machining process, several important operational constraints have been considered. These constraints were taken to account in order to make the model more realistic. A model of the process has been formulated with non-traditional algorithms; GA and PSO have been employed to find the optimal machining parameters for the continuous profile. GA produces better results.

Future Scope

1. The neural network, single objective genetic algorithm and multi objective genetic algorithm and RSM provide a very good process modeling. In addition, the single objective genetic algorithm next multi objective genetic algorithm and next RSM provide the better data coverage value has to be conducted further.
2. In the present work, the cutting conditions such as feed and speed are optimized based on the total production cost, total production time and combined of these two, as objective functions by taking into consideration the various constraints such as feed, cutting speed, power, cutting force, temperature, and surface roughness. Whereas, there are other constraints also such as dimensional accuracy, rigidity and reliability of the system etc. that could also be considered.

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