OPTIMIZATION OF TURNING PARAMETERS IN MACHINING OF THE CAST IRON ROLLS USING GENETIC ALGORITHM

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Abstract :

Rolling mills for rolling of steel may differ in many aspects with each other. The mill rolls steel materials of different cross-sections, sizes and qualities and in material conditions which are either hot or cold. All the rolling mills have rolls for the rolling of materials which are fitted in roll stands. When these rollers are affected to heavy cyclic loads or cracking of rolling elements they may be broken. These broken rollers are replaced with new rollers or existed old rollers after required machining operations.

CNC machines are used to produce finished rolls from cylindrical form or used to redress the existed rolls. These rolls are produced through straight turning, taper and circular machining. In this work spindle speed, feed rate and depth of cut are taken as the machining parameters in turning of rolls. The machining time (M_t) and Tool Life (T_l) are taken as objective function.

This project work aimed at the optimization of turning parameters for the minimum machining time and maximum tool life by using Genetic Algorithm (GA).

This project applies Taguchi's design of experiment methodology and regression analysis (in MINITAB17) for optimization of process parameters in turning of cast iron rolls using tungsten coated carbide insert. Experiments have been carried out based on L9 orthogonal array design with three process parameters namely spindle speed, feed rate and depth of cut for machine time and tool life. The mathematical models have been developed for individual's response using regression analysis. Genetic Algorithm (in MATLAB R2013a) is used for the optimization of objectives to indicate that the significance of three process parameters.

***Key*words- Cast iron rolls, Tungsten coated carbide tool insert, Optimization, Genetic Algorithm.**

I. INTRODUCTION:

The term manufacturing may refer to a range of human activity, from handicraft to high tech, but is most commonly applied to industrial production, in which raw materials are transformed into finished goods on a large scale. Such finished goods may be used for manufacturing other, more complex products, such as house hold appliances or automobiles or sold to wholesalers, who in turn sell them to retailers, who then sell them to end users-the consumers. Among manufacturing processes, metal cutting is unique because it can be used both to create products and to finish products. It is the world's most common manufacturing process, with10 to 15% of the cost of all goods being attributed to it.

Metal cutting is defined as the removal of metal chips from a work piece in order to obtain a finished product with desired attributes of size, shape, and surface roughness. There are different methods of metal cutting and turning is one of the simplest among these methods. Turning is the process of machining external cylindrical and conical surfaces and it is usually performed on a lathe.

In turning operation, it is an important task to select cutting parameters (speed, feed and depth of cut) for achieving high cutting performance. For efficient use of machine tools, optimum cutting parameters are required. So it is necessary to find a suitable optimization method which can find optimum values of cutting parameters for obtaining better result. The turning process parameter optimization is highly constrained and nonlinear. Usually, the desired cutting parameters are determined based on experience or by use of handbook. But the ranges given these sources are actually starting values and are not the optimal values. However, this does not ensure that the selected cutting parameters have optimal or near optimal cutting performance for a particular machine and environment. Optimization of machining parameters not only increases the utility for machining economics, but also the product quality to a great extent. In this context, an effort has been made to estimate the cutting parameters that will minimize the machining time and maximize the tool life into satisfactory level using Genetic Algorithm.

II. LITERATURE SURVEY:

Optimization of process parameters in machining operations has been an area of interest for many researchers since 1950 when Gilbert presented an analytical procedure for determining the optimum spindle speed in a single pass turning operation. The selection of optimal cutting parameters in machining is a difficult task which involves the development of machining models, and optimization algorithms able to handle those models. The problem of the optimal machining condition selection has been analyzed by many researches. Some of the authors analyzed the optimum process parameters that satisfy the basic manufacturing criterions. Basically, this optimization procedure, when ever carried out, involves partial differentiation for the minimization of the machining time and maximization of tool life.

During the machining process, a considerable amount of the spindle speed and feed rate are transferred into the friction of the chip on the tool face and the friction between the tool and the work piece to cut the work piece surface.

Studies that have been done by many researchers verify the relation between the spindle speed and Feed rate. R.Q.sardina and M.R.Santana [**2005**]., S.S.Mahapatra and Amar patnaik [**2006**]., Rituparna Datta and Anima Mazumder [**2010**]., H.Ganesan and G.Mohan Kumar [**2011**]., Iswar Shivakoti and Sunny Diyale **[2012].**, M.Durai Raj and S.Gowri **[2013].**, Wahyu .Widhiarso and Cucuk NurRosyidi **[2018].**, all presented in their work that the increase in spindle speed causes an increase in temperature and this increase will result in wear. With increase of spindle speed, friction increases which are responsible for the increase in temperature in the cutting zone and with the increase in feed rate, spindle speed the machining time will be reduced.

III. EXPERIMENTAL DETAILS:

External longitudinal turning was performed on a powerful rigid lathe (90 KW) of excellent operational condition at different Spindle speeds (S), Feed rates (f) and depth of cuts (d). Fig.3 shows the photo graphic view of the experimental set-up. The work piece material was cast iron roll (Outer Dia 850mm, and length 1250mm) hardened to 50~55 SHC. The cutting tool used was coated tungsten carbide tool (RCMX25). The insert has been clamped in a tool holder. The chemical composition and mechanical properties of work piece material are given below.

C	Si	Mn	P	S	Ni	Cr	Mo
3.30	1.59	0.61	0.051	0.013	1.73	0.40	0.29

Table.1: Chemical Composition.

Roll Size Φ L	Material Grade	Required Hardness	Actual Hardness
850*1200	GCI	50-55 SH C	52/53 SH C

Table.2: Mechanical Properties.

The conditions under which the machining tests have been carried out are briefly given below. A number of spindle speed, feed rate and depth of cut have been taken over relatively wider ranges keeping in view the industrial recommendations for the tool-work materials under taken and evaluation of role of variation in these cutting parameters on the effectiveness of dry machining technique.

Experimental conditions:

Type of Lathe Machine	: 'Waldrich Seizen' CNC Lathe Machine (Germany), 90kW
Work materials	: Cast iron roll (50-55SH C)
Size	: Outer Dia 850mm, and length 1200mm
Cutting tool insert	: Tungsten Coated Carbide, RCMX-25
Process parameters:	
Spindle speed, (S)	: 10, 14, and 18 rpm
Feed rate, (f)	: 1.2, 1.4, and 1.6mm/rev
Depth of cut, (d)	: 8, 9, and 10mm

Fig.1: CNC Turning Machine.

Fig.2: Cutting Tool Insert.

IV. METHODOLOGY:

The present project work is divided into two parts. First of all there is an experimental analysis of the effects of minimum machining time and maximum tool life of the machined part while turning cast iron roll (55 SH C) material with tungsten carbide insert. The other part of the project work is concentrated to the optimization of cutting parameters (spindle speed, feed rate and depth of cut) while turning cast iron rollers by tungsten carbide insert.

The methodology would be as follows:

i. The machining time in turns of minutes has been monitored by a stop watch to study the effect of cutting parameters according to the design of experiments.
ii. The tool life is measured in terms of minutes has been monitored by using mathematical equation as given in table 4.
iii. Optimization of cutting parameters has been done by using Genetic Algorithm (GA). The required data was collected from the experiment of the turning process applied on cast iron rolls. The objective function of the optimization process was to determine the cutting parameter that minimizes machining time and maximizes tool life under certain constraints. Statistical models have been developed to establish the objective function and also the constraints for solving the problem.
iv. The proposed models have been verified by experimental data of turning cast iron rolls by tungsten carbide (TNMG) insert.

Fig.3: Experimental Setup.

Design of Experiments:

In this process three factors at three levels are chosen which is given in table 3. The fractional factorial designed used is a standard L_9 orthogonal array. This orthogonal array is chosen due to its capability to check the interactions among factors. Each row of the matrix represents one trail.

The basic principle in using any design of experiments (DOE) technique is to first identify the key variables in the process and then actively probe those variables to determine their effects on the process output. A typical DOE process consists of three different phases, screening, characterization, and optimization, although not all three phases are used in every study. Orthogonal designs are particularly useful because the estimate of the effect of a factor is unaffected by which other factors are under consideration. Factorial designs, which involve all possible combinations of levels of all the factors, can be investigated simultaneously. This technique also saves time and money because large number of factors can be investigated simultaneously

Levels	Spindle speed S in rpm	Feed rate f in mm/rev	Depth of cut d in mm
1	13	1.2	8
2	15	1.4	9
3	17	1.6	10

Table.3: Cutting Parameters and Levels.

V. EXPERIMENTS CONDUCTED:

S. no	Spindle speed S in rpm	Feed rate f in mm/rev	Depth of cut d in mm	Machining Time Mt (minutes)	Tool Life $T_l = l/(S*f)$ (Minutes)
1	10	1.2	8	85.5	100
2	10	1.4	9	65	85.71
3	10	1.6	10	41	75.00
4	14	1.2	9	77.6	71.42
5	14	1.4	10	55.7	61.22
6	14	1.6	8	70.3	53.57
7	18	1.2	10	60.8	55.55
8	18	1.4	8	80.4	47.61
9	18	1.6	9	53.2	41.66

Table.4: Experiments conducted.

VI. GENETIC ALGORITHM: STEPS INVOLVED

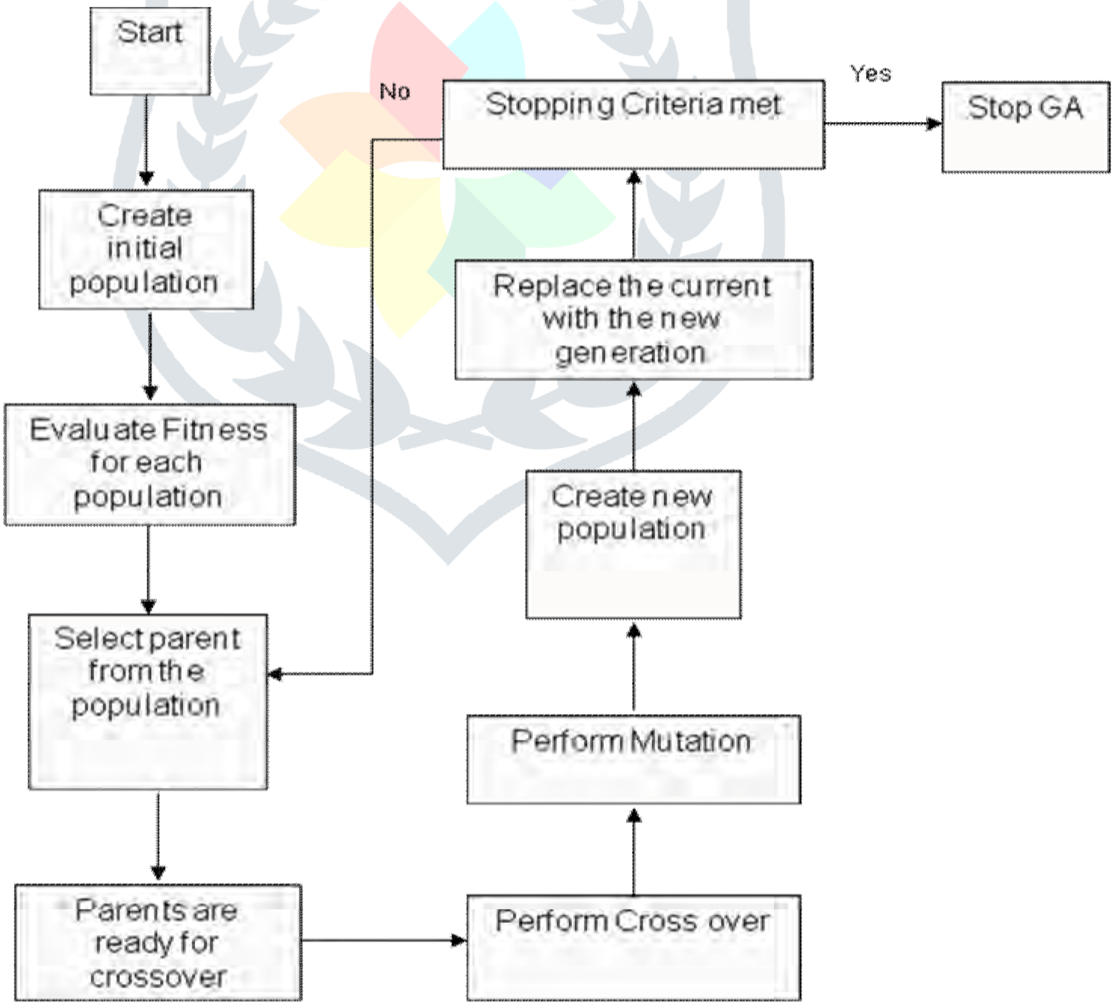


Fig.4: Outline of Genetic Algorithm.

Step 1: The objective functions equations are obtained by using regression analysis in **Minitab 17** software.

Regression Analysis: Mt versus x1, x2, x3.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	1895.37	631.79	50.62	0.000
x1	1	11.76	11.76	0.94	0.376
x2	1	702.00	702.00	56.25	0.001
x3	1	1181.61	1181.61	94.68	0.000
Error	5	62.40	12.48		
Total	8	1957.77			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
3.53272	96.81%	94.90%	87.68%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	262.0	17.2	15.20	0.000	
x1	0.350	0.361	0.97	0.376	1.00
x2	-54.08	7.21	-7.50	0.001	1.00
x3	-14.03	1.44	-9.73	0.000	1.00

Regression Equation

Mt = 262.0 + 0.350 x1 - 54.08 x2 - 14.03 x3

Machining Time can be estimated from the equation given below:

Minimize M_t = 262.0+0.350*x1-54.08*x2-14.03*x3.

Where,
M_t = Machining Time
x_1 = Spindle Speed
x_2 = Feed Rate
x_3 = Depth of Cut

Regression Analysis: T_l versus x1, x2, x3.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	2789.74	929.91	56.89	0.000
x1	1	2238.42	2238.42	136.94	0.000
x2	1	536.57	536.57	32.83	0.002
x3	1	14.76	14.76	0.90	0.386
Error	5	81.73	16.35		
Total	8	2871.48			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
4.04306	97.15%	95.45%	89.78%

```
Coefficients

Term          Coef  SE Coef  T-Value  P-Value   VIF
Constant     213.7     19.7    10.83    0.000
x1          -4.829    0.413   -11.70    0.000  1.00
x2          -47.28     8.25    -5.73    0.002  1.00
x3           -1.57     1.65    -0.95    0.386  1.00


Regression Equation

Tl = 213.7 - 4.829 x1 - 47.28 x2 - 1.57 x3
```

Tool Life can be estimated from the equation given below:

Maximize T_l = 213.7-4.829*x1-47.28*x2 -1.57*x3

Where,

T_l = Tool Life

x_1 = Spindle Speed

x_2 = Feed Rate

x_3 = Depth of Cut

Step 2: Then the optimization is carried out by using MATLAB-R2013a

Step 3: According to Objective functions and constraints a program is needed to run the optimization process. The Structure of the program is given below.

```
function y = bharath(x)
%UNTITLED summery of this function goes here
% It is a multi objective function i.e. more than 1 function
% y(1)....objective 1....@equation for Mt minimize
% y(2)....objective 2....@equation for Tl maximize

% x(1)....spindle speed
% x(2)....feed rate
% x(3)....doc

% Mt
y(1) = 262.0+0.350*x(1)-54.08*x(2)-14.03*x(3)

% Tl
y(2) = 213.7-4.829*x(1)-47.28*x(2)-1.57*x(3)

end.
```

Step 4: Open the Genetic Algorithm solver in optimization tool box in MATLAB and select the parameters according to the problem.

Solver	: Multi objective GA
No. of variables	: 3
Lower bounds	: 10, 1.2, 8
Upper bounds	: 18, 1.6, 10
Population type	: Double Vector
Population size	: 15

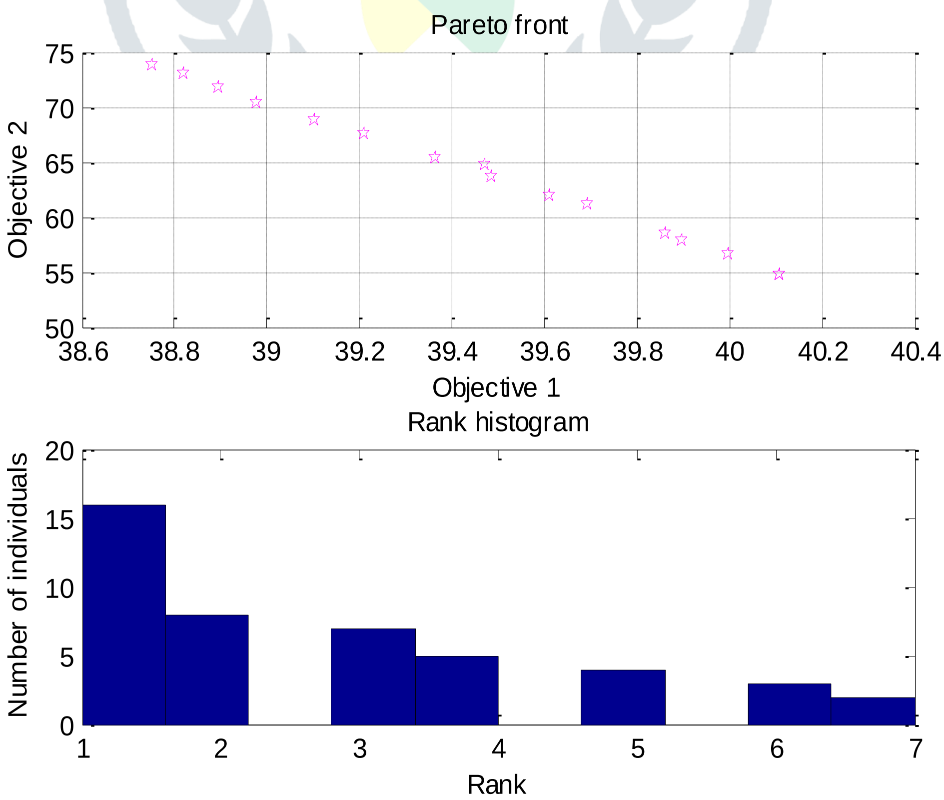
Selection	: Tournament (size 2)
Reproduction	: Crossover fraction- 2, Mutation function- constraint dependent.
Migration	: Forward Direction
Plot functions	: Pareto front, Rank histogram.

Step 5: Run the solver and the till the termination is completed.

Step 6: The results will be obtained as Pareto front optimal values.

S. no	F1	F2	X1	X2	X3
1	40.10	54.75	13.99	1.5999854996	9.9974600589
2	38.75	73.77	10.06	1.599681302	9.9971829852
3	38.81	73.07	10.21	1.5993827897	9.9971357164
4	38.97	70.39	10.76	1.5999651353	9.9972903993
5	39.86	58.45	13.23	1.5996094913	9.9974010938
6	39.99	56.69	13.60	1.5994827739	9.9973930622
7	38.89	71.80	10.47	1.5996617351	9.9971607825
8	39.10	68.83	11.08	1.5997487778	9.9974130192
9	39.36	65.46	11.78	1.5994597584	9.9973492289
10	39.21	67.65	11.33	1.5993954186	9.9971563761
11	39.61	61.99	12.50	1.5995072228	9.9973894026
12	39.89	57.82	13.36	1.5997968704	9.9974398716
13	39.47	64.73	11.94	1.5984822089	9.9973291923
14	39.48	63.69	12.15	1.5995710421	9.9973204329
15	39.69	61.18	12.67	1.5991213872	9.9972385569
16	40.10	54.75	13.99	1.5999854996	9.9974600589

Table.5: Pareto front - Functional values and Decision variables.



Parameters	Predicted Values	Experimental values
Spindle speed (rpm)	10.06	10
Feed rate (mm/rev)	1.59	1.6
Depth of cut (mm)	9.99	10
Machining Time M_t(min)	38.78	41
Tool life T_l (min)	73.77	75

Table.6: Comparison of predicted values and experimental values.

VII. RESULTS:

From the table .5, the optimal values of process parameters for minimum machining time and maximum tool life are given in the table given below.

Parameters	Optimal Values
Spindle speed (rpm)	10.06
Feed rate (mm/rev)	1.59
Depth of cut (mm)	9.99

Table.7: Final optimal values.

VIII. CONCLUSIONS:

- From the table.6, it is concluded that at 10rpm spindle speed, 1.6 mm/rev feed rate, 10mm depth of cut, the minimum value of machining time is 41 minutes and the maximum value of tool life is 75 minutes for 1 pass.
- For the complete machining which is carried out in 2 passes, the final values of machining time and tool life are 82 minutes and 150 minutes.
- After implementation of Optimization by using GA, it is concluded that, at optimal values of process parameters the machine time is reduced to 82 minutes which is 35% less than of machining without optimization.
- The reduced machining time will reduces the cost of machining process. The analysis of cost before and after implementation of optimization by using GA is given in the below table.

	Operating cost per hour (Rs/-)	Total operating cost (Rs/-)
Before Optimization	7000/-	12996/- (for 111.4 minutes)
After Optimization	7000/-	9566/- (for 82 minutes)

Table.8: Analysis of operating cost.

- Finally it is concluded that by implementing Optimization technique, the amount of savings in operating cost is Rs. 3430/- on completion of one job.
- After implementation of Optimization by using GA, it is concluded that, at optimal values of process parameters the tool life is increased to 75 minutes which is 25% more than of machining without optimization.
- The increased tool life will reduces the tool cost and machining time. The analysis of tool life before and after implementation of optimization by using GA is given in the below table.

	Tool life (minutes)
Before Optimization	60
After Optimization	75

Table.9: Analysis of Tool life.

IX. ACKNOWLEDGEMENTS:

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