Analysis and Optimization of cutting parameters of Carbon Steel EN8D used in the Shaft of Crawler Excavator under Carriage Track Roller Assembly for Model PC 200

1Ghanshyam V. Patel
1Head of the Department
1Swaminarayan college of Engineering and Technology

Abstract 聽- **Excavators are popular earthmoving vehicles that consists of a bucket, arm, rotating cab, and movable tracks. These components provide superior digging power and mobility, allowing this heavy equipment to perform a variety of functions. Currently, Industries which uses crawler excavators having Carbon Steel material for movable track roller are facing problem of strength, weight and high cost of track roller material and processes. Hence, selection of proper relevant material and its manufacturing processes will be done which could increase strength as well as decrease weight and overall cost of excavator under carriage track roller assembly parts. Thus, after suitable identification of materials and manufacturing process of track roller assembly parts, optimization and analysis will be done to confirm selected materials. In the present work, by using Taguchi approach, the Turning of EN-8D carbon steel is carried out in order to optimize the turning process parameters. The present paper deals with the optimization of selected process parameters, i.e., Speed, Feed rate, Depth of cut . Taguchi orthogonal array is designed with three levels of machining parameters and different experiments are done using L9 (3^3) orthogonal array. Taguchi method stresses the importance of studying the response variation using the signal to noise (S/N) ratio, resulting the minimization of quality characteristic variation due to uncontrollable parameter. Predicted value of cutting parameters and verification test values are valid when compared with the optimum value. It is found that optimum value of verification test is within the limits of predicted value and the objective of the work is full filled.**

Keywords - **Crawler excavator, track roller, Taguchi Method, Optimization, EN-8D carbon steel, turning, signal to noise (S/N) ratio etc.**

I. Introduction

In recent time, a major research is focused on the uses of reduction of material and cost, keeping desired quality. In general, manufacturing process is classified as primary and secondary processes. The Casting, Welding, Forging, etc. comes under primary manufacturing processes and the machining comes under secondary manufacturing process. The selection of objectives of this work includes the validation using surface roughness and the machining time, are the basic critical factors for production time and the surface roughness (Ra) is the most important criteria that to be reduced as far as possible because of its effect of leading to failure in the mating parts due to friction. The work material used for the present study is carbon steel EN8D. It is suitable for shafts, Medium torque shafts, studs, bolts, connecting rods, screws, rollers, hydraulic ram. It is mostly used in Automobile parts and machine building industry. EN8D carbon steel is a common medium carbon and medium tensile steel, with improved strength over mild steel, through hardening medium carbon steel. It is also readily machinable in any condition, also known as 080A40. An unalloyed medium carbon steel, EN8D is a medium strength steel and good tensile strength, suitable for shafts, stressed pins, studs, keys etc. These steels are generally used as supplied untreated condition. But EN8D steels can be further surface-hardened by induction processes, producing components to withstand wear resistance. These materials, in its heat-treated forms possesses good homogenous metallurgical structures, giving consistent machining properties.

TRACK & CARRIER ROLLERS: Friction and shock loads transmitted from the track chain create heat within the roller. To withstand this, several quality steps are taken in the manufacturing of Komatsu Genuine OEM rollers. Komatsu rollers are constructed of long wearing, heat resistant stellite material supported by rubber load rings that keep oil in and dirt out. Highly polished shafts and bronze bushings are used in Komatsu OEM rollers to reduce friction and extend roller life. Rollers have heat treated tread and flange areas for increased strength and longer wear life. Heavy duty mounting brackets secure rollers to track frames allowing the transmission of shock loads throughout the track frame, thereby reducing potential damage. Reservoir cavities in roller shells and shafts feed lubricant throughout the roller’s interior to reduce damage-causing heat. Surface hardness of the roller’s outer shell reduces the wear caused by friction. Hardness decreases toward the inner bore to avoid brittleness and provide absorption of shock loads. Greater flange height on Komatsu OEM rollers provides maximum track alignment and machine stability under any operating conditions. Depending on the application, you can choose from a wide range of track rollers. Standard and single flange with internal lubrication. Designed to offer track alignment during operation.

This track roller has a different seal to withstand cold temperatures and maintain elasticity. EN8D is a very popular grade of through-hardening medium carbon steel, which is readily machinable in any condition. EN8D is suitable for the manufacture of parts such as general-purpose axles and shafts, gears, bolts and studs. It can be further surface-hardened typically to 50-55 HRC by induction processes, producing components with enhanced wear resistance. For such applications the use of EN8D (080A40) is advisable. EN8D in its heat-treated forms possesses good homogenous metallurgical structures, giving consistent machining properties. Good heat treatment results on sections larger than 63mm may still be achievable, but it should be noted that a fall-off in mechanical properties would be apparent approaching the center of the bar. It is therefore recommended that larger sizes of EN8D are supplied in the untreated condition, and that any heat treatment is carried out after initial stock removal. This should achieve better mechanical properties towards the core.

CNC lathe MONO 200 Specifications:

Table 1 CNC lathe specification (MONO 200)

Chuck Size	200 mm
Weight	3800 Kg
Max Turning length	550mm
Max turning Diameter	350mm
Rapid Feed	24 m/min(x/z)
Spindle Bore	63 mm
Spindle Nose	A2-6
Spindle Power	7.5/11 kW
Std. turning Diameter	200 mm
Travel	185/550 mm (x/z)

Fig. 1 Surface roughness measurement device

Table 2 SURFTEST SJ 210 Specification

Measuring range X axis	0.69" (17.5mm)
Make	Mitutoyo
Filters	Gaussian, 2CR75, PC75
Sampling length	0.003, 0.01, 0.03, .1 " (0.08 , 0.25 , 0.8 , 2.5mm)
Display languages	Japanese, English, German, French, Italian, Spanish, Portuguese, Korean, Traditional Chinese,
Power-saving function	Auto-sleep off function (10-600sec) *3

II TAGUCHI Philosophy

The Taguchi Method is developed by Dr. Genichi Taguchi. Generally, a number of Experiments based on a number of selected Parameters. Higher number of Parameters means a greater number of trials, which is time consuming. It is aid to modify the levels of Parameters included in the experiments. This method serves to cut the number of trials by modifying the parameters involved in the experiment so that less time is taken for the experiment and also not much need for more fatigue calculations. The purpose of the Taguchi method is to investigate control variable settings that produce satisfactory responses and contempt natural environmental and process variability. In each experiment, Taguchi's design approach utilizes two designs called the inner and outer array. This method is the cross product of these two arrays. The control variables, used to tweak the procedure, from the inner array. The noise variables, related to process or environmental variability, from the outer array.

Selection of Parameters and Their Levels:
The variable parameters are Speed in rpm, Feed in mm/rev, Depth of Cut in mm, have been used in this experiment by keeping types of coolant and tool bit are kept constant in the entire experiment. Selected parameters and their level for the experiment are shown in a Table below.

Table 3 Factors & Levels

Factors / Level	Speed (rpm)	Feed (mm / min)	Depth Of Cut (mm/rev)
1	400	0.15	0.5
2	600	0.3	1.0
3	800	0.4	1.5

Selection of Orthogonal Array:
"Orthogonal array" is the key factor of this method. Orthogonal array helps to study a total number of variables by considering only a few trials. There are various types of orthogonal arrays available in "Minitab software".

Orthogonal array = Lx (L^F)
Where, x = Number of Experiments
F = Number of Factors
L = Number of Levels

In this research study 3 levels and 3 factors have taken, by Taguchi design of experiment method following arrays and steps of design have made.

L9(3^3)
Number of Experiments = 9
Number of Factors = 3
Number of Levels = 3

Table 3 is made from the software "MINITAB" as per the step shown in upper narration, so in the orthogonal arrays, the input parameters are taken which has the proper values i.e., Speed, Feed, Depth of Cut are the variable parameters for the experiments. Speed is in 3 levels (400, 600, 800 rpm, Feed is in 3 levels (0.15, 0.30, 0.40 mm) and Depth of cut is in 3 levels (0.5, 1.0 1.5).

Table 4 Orthogonal Array

Experiment Numbers	Column		
	Speed rpm	Feed mm/rev	Depth of Cut mm
1	400	0.15	0.5
2	400	0.3	1
3	400	0.4	1.5
4	600	0.15	1.0
5	600	0.3	1.5
6	600	0.4	0.5
7	800	0.15	1.5
8	800	0.3	0.5
9	800	0.4	1

Table 5 Machining time and Surface roughness

Exp. No.	Machining Time (MT) sec	Surface Roughness (Ra) µm
1	30	3.12
2	16	3.24
3	13	4.321
4	21	2.826
5	12	2.913
6	10	3.968
7	17	1.045
8	8	3.059
9	8	4.454

III Taguchi's Design of Experiment (DOE) Method:

Taguchi derived a method for reducing the number of experiments and increasing the speed of the experiment process. By using this method, the effective solutions will be generated. Orthogonal Array (OA) are substantial parts of Taguchi method. The OA is an alternate solution for factorial design and has ability to evaluate some factors in a minimal number of tests. This method is reasoned as an effective technique as much result was obtained from a few trials. The Signal-Noise ratio of Taguchi method is a troupe of virtue and relates inversely to the loss function. It is identified as the ratio of amount of energy for specified function to amount of energy squandered. With the concept of SN (Signal-Noise) ratio the various quality characteristics can be analyzed using the method to accomplish high quality products. By following this step optimum set of parameters will be found out and based on that result final conclusion will give optimum set.

The steps involved in Taguchi's DOE (Design of Experiment) method are:

1. Discovering the response functions and control parametric quantity to be measured.
2. Deciding number of stages of control parameter.
3. Choosing the advantageous orthogonal array, assigning the parameters to the array and directing the experiment.
4. Analysing the experiment results and taking the optimal levels of control parameters.

Analyzing Experimental Data:

For the case of minimizing the performance characteristic:

$$SN = -10\log(\sum y^2/N)$$

For the case of maximizing the performance characteristic,:

$$SN = -10\log(\sum (1/y^2)/N)$$

Steps followed in analysis methodology are as follows, which are completely based on a Taguchi method.

1. Specify a goal which is to find out the best set of parameters.
2. Based on that select appropriate response for optimization.
3. Once responses are selected, select factors and levels for the optimization.
4. Select Orthogonal Array.
5. Conduct Taguchi's analysis.
6. Based on analysis, determine optimum set of parameters.
7. Find out predicted values for that set.
8. Compare predicted values with experiment values which is validation of experiment.
9. If error is nearer, then stop the analysis otherwise select a new set and continue the process.

Taguchi Analysis: RA versus SPEED, FEED, DOC

Table 6 Signal to Noise ratios for RA (Smaller is better)

Level	SPEED	FEED	DOC
1	-10.935	-6.430	-10.522
2	-10.094	-9.736	-10.736
3	-7.690	-12.553	-7.460
Delta	3.246	6.123	3.276
Rank	3	1	2

Table 7 Means for RA

Level	SPEED	FEED	DOC
1	3.560	2.330	3.382
2	3.236	3.071	3.507
3	2.853	4.248	2.760
Delta	0.708	1.917	0.747
Rank	3	1	2

Fig. 2 Mean for RA

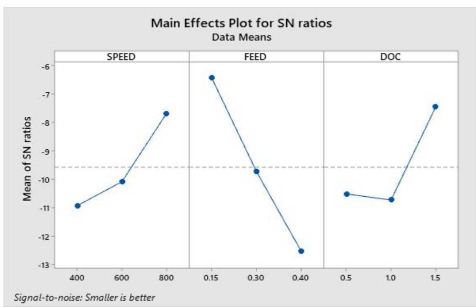

Fig. 3 S/N ration for RA

Table 8 Optimum set of parameters for surface roughness

Sr no	Control Factor	Optimum Level	Value
1	SPEED	3	800
2	FEED	1	0.15
2	Depth of cut	3	1.5

Taguchi Analysis: MT versus SPEED, FEED, DOC

Table 9 Signal To Noise Ratios for MT(Smaller is better)

Level	SPEED	FEED	DOC
1	-25.30	-26.87	-22.53
2	-22.68	-21.24	-22.86
3	-20.24	-20.11	-22.82
Delta	5.06	6.75	0.33
Rank	2	1	3

Table10 Means for MT

Level	SPEED	FEED	DOC
1	19.67	22.67	16.00
2	14.33	12.00	15.00
3	11.00	10.33	14.00
Delta	8.67	12.33	2.00
Rank	2	1	3

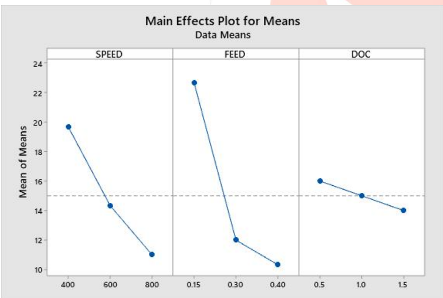

Fig. 4 Plot for Means

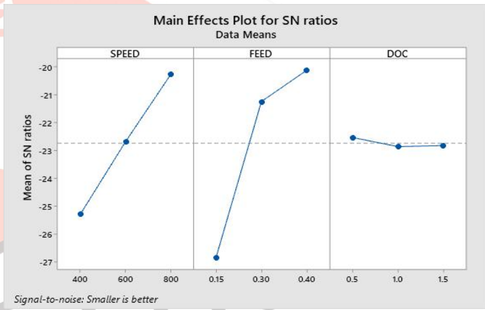

Fig. 5 Plot for SN ratios

Table 11 Optimum set of parameters for machining time

Sr no	Control Factor	Optimum Level	Value
1	SPEED	3	800
2	FEED	3	0.4
2	Depth of cut	1	0.5

IV Regression analysis:

RA versus SPEED, FEED, DOC:

Mathematical Relationship between the Input Parameters and Surface Roughness:

The mathematical relationship for correlating the Surface roughness and the considered process variables has been obtained as follows using coefficient from table 12.

Regression Equation

$$RA = 2.79 - 0.000177\ SPEED + 7.45\ FEED - 0.623\ DOC$$

Table12 Coefficients

Term	Coeff	SE Coeff	95% CI	T-Value	P-Value
Constant	2.79	1.03	(0.14, 5.44)	2.71	0.042
SPEED	-0.00177	0.00119	(-0.00483, 0.00129)	-1.49	0.197
FEED	7.45	1.89	(2.59, 12.32)	3.94	0.011
DOC	-0.623	0.476	(-1.847, 0.601)	-1.31	0.248

Table 13 Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	6.6105	79.54%	6.6105	2.2035	6.48	0.036
SPEED	1	0.7512	9.04%	0.7512	0.7512	2.21	0.197
FEED	1	5.2777	63.50%	5.2777	5.2777	15.52	0.011
DOC	1	0.5816	7.00%	0.5816	0.5816	1.71	0.248
Error	5	1.7003	20.46%	1.7003	0.3401		
Total	8	8.3108	100.00%				

- Error in contribution is 20.46 % which is due to external factors cannot be controlled during experiment.
- In regression analysis contribution of feed is 65.5%, higher compare to other cutting parameter as shown in above table 13 and lowest contribution is having depth of cut 7%. So in surface roughness, feed is important by which minimum roughness can be achieved with high speed. For P-value whichever is less than 0.05 indicates good value.

Normal Probability Plot for RA:

The normal probability plot in the Fig. 6 shows a clear pattern (as the points are almost in a straight line) indicating that all the factors and their interaction given in are affecting the RA. In addition, the errors are normally distributed and the regression model is well fitted with the observed values.

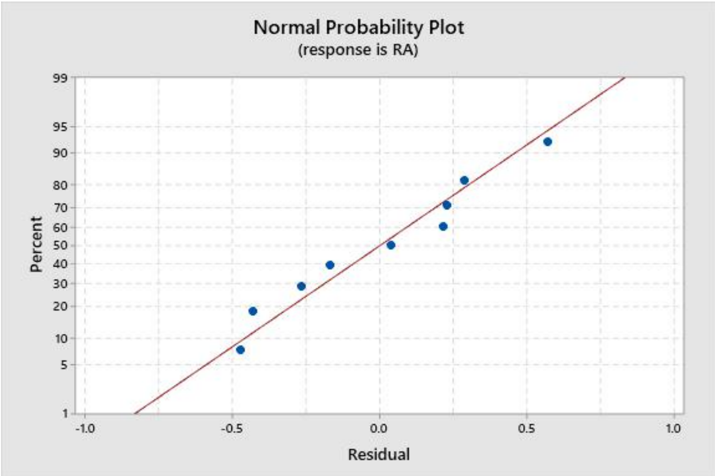

Fig.6 Normal probability plot for RA

MT versus SPEED, Feed, DOC:

Mathematical Relationship between the Input Parameters and machining time:

The mathematical relationship for correlating the machining time and the considered process variables has been obtained as follows using coefficient from table 14.

Regression Equation:

MT=44.46-0.02167 SPEED -51.05 FEED-2.00 DOC

Table 14 Coefficients for MT

Term	Coef	SE Coef	95% CI	T-Value	P-Value
Constant	44.46	4.72	(32.32, 56.61)	9.41	0.000
SPEED	-0.02167	0.00546	(-0.03569, -0.00764)	-3.97	0.011
FEED	-51.05	8.67	(-73.35, -28.76)	-5.89	0.002
DOC	-2.00	2.18	(-7.61, 3.61)	-0.92	0.402

Table 15 Analysis of Variance for MT

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	366.272	91.11%	366.272	122.091	17.09	0.005
SPEED	1	112.667	28.03%	112.667	112.667	15.77	0.011
FEED	1	247.605	61.59%	247.605	247.605	34.65	0.002
DOC	1	6.000	1.49%	6.000	6.000	0.84	0.402
Error	5	35.728	8.89%	35.728	7.146	\	

- Error in contribution is 8.89 % which is due to external factors cannot controlled during experiment.
- In regression analysis contribution of feed is 61.59, higher compare to other cutting parameter as shown above table 15 and lowest contribution is having depth of cut 1.49%. So in machining time feed is an important by which maximum material can be removed within less time. For P – value whichever is less than 0.05 indicates good value.

Normal Probability Plot for MT: The normal probability plot in the Fig. 7 shows a clear pattern (as the points are almost in a straight line) indicating that all the factors and their interaction given in are affecting the Machining time. In addition, the errors are normally distributed and the regression model is well fitted with the observed values.

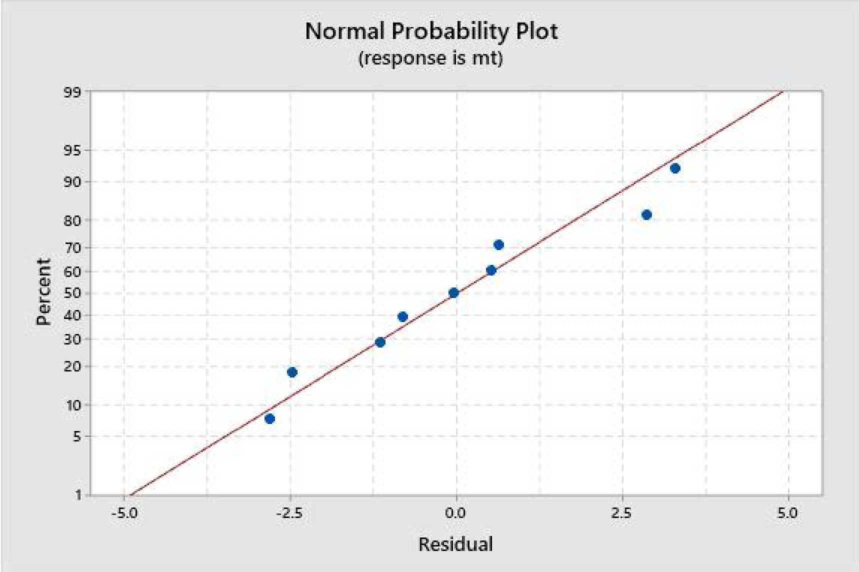

Fig.7 Normal probability plot for MT

Prediction for surface roughness:

Table 16 Optimum Parameters for Surface Roughness

Factors Optimum Parameter	Values
Cutting Speed(rpm)	800
Feed Rate(mm/min)	0.15
Depth of Cut(mm)	1.5

Prediction for machining time:

Table 17 Optimum Parameters for machining time

Factors Optimum Parameter	values
Cutting Speed(rpm)	800
Feed Rate(mm/min)	0.4
Depth of Cut(mm)	0.5

Validation of Experiment:

Run the Experiment by taking the optimum parameter set given by the response curve analysis. Outcome of this experiment has been compared with the actual values of optimal set.

Actual Experiment for Validation:

- For validation of surface roughness Cutting parameter: Speed (rpm) 800, Feed Rate (mm/min) 0.15, Depth of Cut (mm) 1.5.
- For validation of machining time Cutting parameter: Speed (rpm) 800, Feed Rate (mm/min) 0.4, Depth of Cut (mm) 0.5.
- As per predicted parameter another experiment performed by maintaining same dimension and machining condition.
- Machining time is measured during machining and surface roughness is measured by surf-test (SJ210).

Confirmation Test for Surface Roughness and Machining Time:

This optimum settings combination is validated by conducting confirmation test. It is concluded that the results are within the acceptable limits of the predicted value and can be implemented in the real time application.

- The Taguchi method was a good method to find out the optimum combinations. The predictions using Taguchi's parameter design technique is adequate agreement with the confirmation results, with a confidence interval of 90%, and this technique saves 75% of the time taken to perform the experiment in this research.
- The objective of the present work is to find out the set of optimum parameter in order to improve surface roughness and reduce machining time considering the control factors for the EN8D work piece material.

V Conclusion

In the present work, Optimization problem has been solved by using an optimal parametric combination of input parameters such as Speed, Feed and Diameter on CNC lathe. These optimal parameters ensure in producing high surface quality turned product. Taguchi method is successfully implemented for optimizing the input parameters. This project produces a direct equation with the combination of controlled parameters which can be used in industries to know the value of surface roughness. The implementation of this gives direct equation in manufacturing industries

- Reduces the manual effort
- Reduces the production cost
- Reduces the manufacturing time.
- Increases the quality of the product which is the ultimate goal of an industry.

Optimum cutting parameters:
For surface roughness:

Speed is 800 rpm, feed is 0.15 mm/rev, Depth of cut is 1.5mm

For machining time:

Speed is 800 rpm, feed is 0.40 mm/rev, Depth of cut is 0.5mm.

- It is found that values of speed, feed & depth of cut are within the limits of the predicted value and the objective of the work is full filled.
- Analysis of variance suggests that feed is the most significant factor for both surface roughness and machining time followed by speed. Whereas, Depth of Cut has very little effect.

VI Scope Of The Future work :

- This experiment can be done for the same cutting parameters by other DOE methods or other optimization techniques.
- This method can also be used for alternative material type.
- From concluding remarks, it is clear that EN8D can be used as a track roller shaft. EN8D has good performance characteristics. There are so many experiments carried out.

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