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Investigating the influencing process parameters in conventional Turning of AISI 1020 carbon steel using Taguchi approach

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Abstract - **AISI 1020 carbon steel is a commonly used in industry for simple structural applications such as cold headed bolts, chain, hard wearing surfaces and gears. It has a good combination of strength and ductility and can be hardened or carburized. Experimental investigation is attempted to study the influence of process parameters on machinability of AISI 1020 using conventional turning process. The experiment is designed with L9 Orthogonal Array (OA) using Taguchi Approach. The four process parameters considered are spindle RPM, feed rate, depth of cut and rake Angle. The material used for Cutting Tool is HSS. Effect of individual parameters on cutting forces are analysed by Analysis Of Variance (ANOVA) and further explained with graphical representation. The optimum machining parameters are obtained by analysis of signal to noise ratio. The experimental results obtained from confirmatory experiment are compared with the results predicted by ANOVA and the Taguchi approach. Confirmatory experiments verified the adequacy of optimal combination of process parameters to achieve minimum cutting forces.**

Keywords **-** Taguchi approach, ANOVA, Spindle RPM, Orthogonal Array, Rake angle, Feed Rate, Depth of Cut, Turning.

1. INTRODUCTION

The hard turning process is recognized as the single point turning of materials with hardness from 50 to 70 HRc. For hard turning to be a viable technology, there are still several issues—including tool life, part integrity, and machine stiffness requirements etc [10]. The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact[3, 12-14]. Even though the machine tool industry has made tremendous progress, the metal cutting industries continue to suffer from a major drawback of not running the machine tools at their optimum operating conditions. The problem of arriving at the optimum levels of the process parameters has attracted the attention of the researchers and practicing engineers for a very long time. Turning is the primary operation in most of the production processes in the industry, cutting forces on tool during turning have great influence on the life of the cutting tool. Cutting forces in turning has been found to be influenced in varying amounts by a number of factors such as feed rate, work material characteristics, cutting speed, depth of cut, cutting time, tool nose radius and tool cutting edge angles, stability of machine tool and workpiece setup, chatter, and use of cutting fluids[5]. The machine tool and its components must be able to withstand these forces without causing significant deflections, vibrations, or chatter during the operation. There are three principal forces during a turning process:

- The **cutting or tangential force** acts downward on the tool tip allowing deflection of the workpiece upward. It supplies the energy required for the cutting operation.
- The **axial or feed force** acts in the longitudinal direction. It is also called the feed force because it is in the feed direction of the tool. This force tends to push the tool away from the chuck.
- The **radial or thrust force** acts in the radial direction and tends to push the tool away from the workpiece.

A quantitative understanding of cutting forces under hard turning conditions is a critical element in addressing these issues because of its implications on thermal analysis, tool life analysis, chatter analysis, etc [10]. AISI 1020 is a low hardenability and low tensile carbon steel with Rockwell hardness of 60-65 and tensile strength of 410-790 MPa. It has high machinability, high strength, high ductility and good weldability. It is normally used in turned and polished or cold drawn condition. This paper presents the study of various cutting parameters and tool geometry for the optimization of cutting forces on AISI 1020 carbon steel. The composition of AISI 1020 Steel is C (0.18% - 0.23%), Mn (0.3% - 0.6%), P (0.04%), S (0.05 %) and Fe (99.08% - 99.43%).

The Taguchi method is statistical tool, adopted experimentally to investigate influence on cutting forces by cutting parameters such as cutting speed, feed and depth of cut. To identify the parameters those affects the machining performance (in terms of cutting forces) and the quality of the components machined by turning a preliminary study was conducted, the parameters for machining can be classified as following:

Machine based parameters**:** These are spindle speed, feed rate, depth of cut and cutting tool.

Coolant based parameters**:** These are the supply of coolant, type of coolant.

Workpiece based parameters**:** These are the workpiece geometry, dia. of workpiece, chemical composition of the workpiece material.

Cutting tool based parameter**:** These are the material of tool, shape of tool, nose radius of tool.

Parameters selected for this experiment based on their availability on the machine are spindle speed, feed rate, depth of cut, back rake angle.

The Taguchi Method:

The Taguchi method(TM) is a powerful problem solving technique for improving process performance, yield and productivity. It reduces scrap rates, rework costs due to excessive variability in processes. To achieve desirable product quality by design, Taguchi recommends a three stage process: system design, parameter design and tolerance design. While system design helps to identify the working levels of the design parameters, parameter design seeks to determine the parameter levels that produce the best performance of the product/process under study. Noise factors are those which are either too difficult or too expensive to control under normal production conditions [3]. The major noise factors in the experiment are reaction time of the operator and operator-to-operator variation. The signal to noise ratio can be divided to 3 categories when characteristic is continuous,

a) Nominal the best
b) Smaller the better
c) Larger the better

The optimal condition is selected so that influence of uncontrollable factor (noise factor) causes minimum variation to system performance.

Experimental setup:

In this experiment Cutting force which acts on a single point cutting tool during turning is taken as the relevant performance characteristic.
Spindle Speed, Feed rate, Depth of Cut and Back Rake angle are the control factors which are optimised to obtain the minimum cutting force. Reaction time of operator and Environmental conditions play the role of Noise Factors.
Three factor levels for each of the control factor was selected which resulted in the degree of freedom of ‘2’ associated with each factor. Table 1 shows the significant values of the control factors

Table 1: Control factors and their range of settings of the experiment.

Label	Control Factor	Level 1	Level 2	Level 3
A	Spindle Speed (rpm)	130	215	340
B	Feed Rate (mm/rev)	0.1	0.45	0.8
C	Depth Of Cut	.2	.3	.4
D	Back rake angle (Degrees)	0.7	5.3	9.2

The total degrees of freedom for this experiment comes out to be 8 (4*2). Hence among all the standard orthogonal arrays, L9 Orthogonal Array was designed. The cutting forces were measured using a dynamometer and values of Tangential force (F_t) and Feed force (F_{feed}) and Radial force (F_r) in kgf were obtained. Table 2, 3 and 4 shows the obtained values of tangential, feed, and radial forces respectively in L9 orthogonal array.

Table 2: Experimental layout (DOE) and tangential forces.

Factors	A	B	C	D	Tangential force (kgf)		
					I	II	III
1	1	1	1	1	17	16	17
2	1	2	2	2	50	45	48
3	1	3	3	3	78	76	75
4	2	1	2	3	20	20	20
5	2	2	3	1	62	60	58
6	2	3	1	2	82	76	71
7	3	1	3	2	28	28	25
8	3	2	1	3	51	53	53
9	3	3	2	1	102	105	114

Table 3: Experimental layout (DOE) and Feed forces.

Factors	A	B	C	D	Feed force (kgf)		
					I	II	III
1	1	1	1	1	6	4	7
2	1	2	2	2	15	19	18
3	1	3	3	3	17	15	24
4	2	1	2	3	9	11	11
5	2	2	3	1	16	16	18
6	2	3	1	2	17	19	19
7	3	1	3	2	8	7	9
8	3	2	1	3	13	11	9
9	3	3	2	1	24	20	22

Table 4: Experimental layout (DOE) and Radial forces.

Factors	A	B	C	D	Radial force (kgf)		
					I	II	III
1	1	1	1	1	4	4	4
2	1	2	2	2	19	14	20

3	1	3	3	3	33	30	27
4	2	1	2	3	3	3	2
5	2	2	3	1	12	14	16
6	2	3	1	2	19	21	25
7	3	1	3	2	4	4	3
8	3	2	1	3	12	10	10
9	3	3	2	1	24	24	26

The net cutting forces were obtained using the formula-

$$Cutting\ force\ (F) = [(F_t)^2 + (F_{feed})^2 + (F_r)^2]^{½}.$$

Table 5 shows the cutting force obtained in L9 orthogonal array.

Table 5: Experimental layout (DOE) and Resultant forces.

Factors	A	B	C	D	Resultant cutting force (kgf)			Average cutting force.
					I	II	III	
1	1	1	1	1	18.466	16.971	18.812	18.083
2	1	2	2	2	55.552	50.813	55.027	53.797
3	1	3	3	3	86.383	83.072	83.247	84.234
4	2	1	2	3	22.36	23.022	22.913	22.690
5	2	2	3	1	65.196	63.655	62.801	63.884
6	2	3	1	2	85.872	81.104	77.634	81.537
7	3	1	3	2	29.394	29.138	26.739	28.424
8	3	2	1	3	53.981	55.095	54.680	54.569
9	3	3	2	1	107.498	109.549	118.978	112.008

ANALYSIS AND CALCULATION

Experimental results for cutting force illustrated in table 5 are analysed using ANOVA software. The 'signal to noise ratio' (S/N ratio) was calculated using the formula of "smaller the better" for minimum cutting forces

$$S/N\ ratio = -10log10\ [1/n * \sum yi\text{^}2]$$

Table 6 shows the calculated S/N ratio for cutting test of AISI 1020 steel.

Table 6: Signal to noise ratio table

Trial no.	Cutting forces			S/N ratio
	I	II	III	
1	18.466	16.971	18.812	-25.154

2	55.552	50.813	55.027	-34.622
3	86.383	83.072	83.247	-38.510
4	22.36	23.022	22.913	-27.118
5	65.196	63.655	62.801	-36.106
6	85.872	81.104	77.634	-38.234
7	29.394	29.138	26.739	-29.081
8	53.981	55.095	54.680	-34.739
9	107.498	109.549	118.978	-40.994

The average S/N ratio were obtained and tabulated (Table 7) for the optimum values. For example average S/N ratio at level 1 for cutting speed (A) = 1/3 * [(-25.154) + (-34.622) + (-38.510)] = -32.762.

Table 7: Average S/N ratio Table

Factor of interaction	A	B	C	D
S/N ratio 1	-32.762	-27.118	-32.709	-34.084
S/N ratio 2	-33.819	-35.156	-34.244	-33.979
S/N ratio 3	-34.938	-39.246	-34.566	-33.456

The response table shows the change of S/N ratio when setting of control factor was changed from one level to another. The table shows the most dominant factor playing role in variation of the cutting forces. The greater the modulus of the difference the significant is the role played by the control factors.

Table 8: Effect estimate of the control factors.

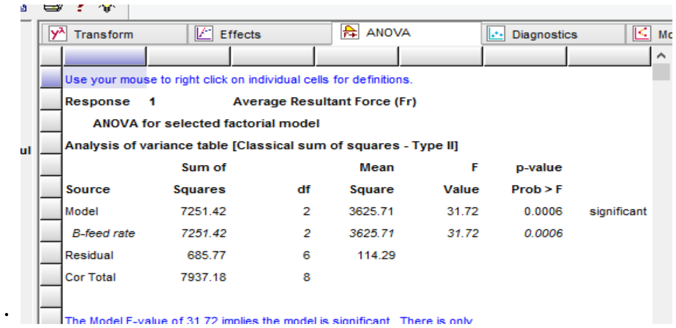
Factors	A	B	C	D
S/N ratio 1	-32.762	-27.118	-32.709	-34.084
S/N ratio 3	-34.938	-39.246	-34.566	-33.456
Difference	**2.176**	**12.128**	**1.857**	**0.628**

RESULT AND DISCUSSIONS

The S/N ratio table (table 7) the various optimum values for all control factors giving minimum value of cutting force are obtained and is represented in following table.

Control factor	**Notation**	**Optimum level**	**Optimum value**
Spindle speed (rpm)	A	1	130
Feed rate (mm)	B	1	0.1
Depth of cut (mm)	C	1	0.2
Back Rake Angle (^{o})	D	3	9.2

Analysis of variance (ANOVA) was performed on most significant factor ‘feed rate’ using Design Expert software. Result are shown below



Use your mouse to right click on individual cells for definitions.

Response 1 Average Resultant Force (Fr)

ANOVA for selected factorial model

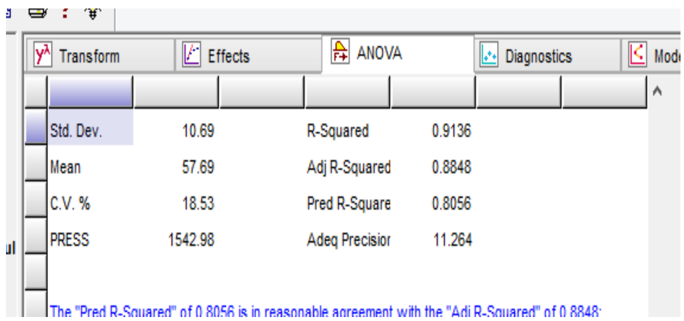
Analysis of variance table [Classical sum of squares - Type II]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	7251.42	2	3625.71	31.72	0.0006	significant
B-feed rate	7251.42	2	3625.71	31.72	0.0006	
Residual	685.77	6	114.29			
Cor Total	7937.18	8				

The Model F-value of 31.72 implies the model is significant. There is only

The model F- value of 31.72 implies the model is significant. There is only 0.06 percent chance that F-value this large could occur due to noise.

Value of “Prob > F” less than 0.050 indicate that the model terms are significant. In this case “B” is a significant model term.

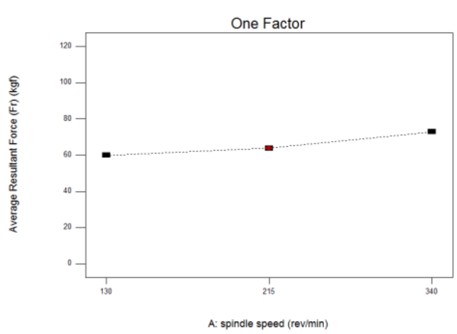


Std. Dev.	10.69	R-Squared	0.9136
Mean	57.69	Adj R-Squared	0.8848
C.V. %	18.53	Pred R-Square	0.8056
PRESS	1542.98	Adeq Precisior	11.264

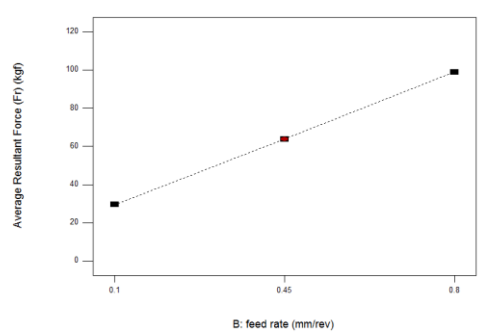
The "Pred R-Squared" of 0.8056 is in reasonable agreement with the "Adj R-Squared" of 0.8848;

The “Pre R-Squared” of 0.8056 is a reasonable agreement with the “Adj R-Squared” of 0.8848; i.e. difference is less than 0.2.”Adeq Precision” measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio is 11.264 indicates an adequate signal. This model can be used to navigate the design space.

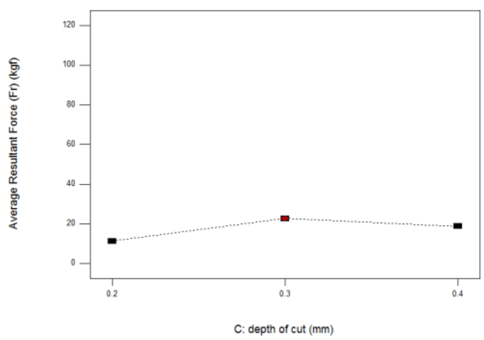
Graphs Obtained:



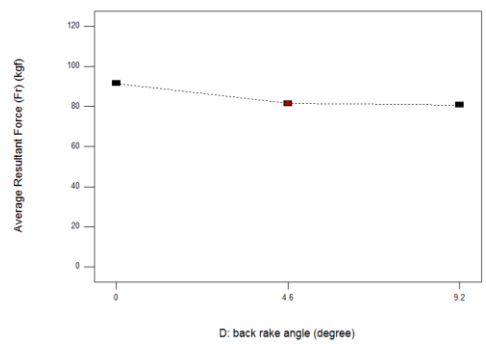
GRAPH : 1



GRAPH :2



GRAPH :3



GRAPH : 4

Verification Experiment:

A verification experiment was done using the obtained optimum values of the control factors (A1, B1, C1, and D3) and readings are tabulated below.

Table 9:

Factors	A	B	C	D	Thrust force			Feed force			Radial forces		
					I	II	III	I	II	III	I	II	III
10	1	1	1	3	9	8	10	4	4	3	2	3	3

Hence the average resultant of force is (10.050 + 9.434 + 10.863)/3 i.e. 10.116.

CONCLUSION

The following conclusions may be drawn for various cutting conditions in machining the En 13 steel by HSS cutting tool.

- The table 8 shows that the most significant control factor is feed rate (B) for the cutting forces followed by Spindle speed (A), Back rake angle (D) of cutting tool plays a very little role in variation of the cutting forces.
- The graph cutting force vs. cutting speed is increasing with increase in spindle speed (graph 1).
- Cutting forces increases linearly with increase in feed rate (graph 2).
- The plot cutting forces vs. depth of cutting is also increasing but nonlinear (graph 3).
- Back rake angle on increasing reduces the Cutting forces (graph 4).
- The verification experiment shows that the cutting forces get reduced by 82.466% from average cutting force value when operated at optimum values, and by 6.855kgf from the minimum value of cutting force in table 5.
- The analysis of variance is significant for Feed Rate.

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