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OPTIMIZATION OF METAL REMOVAL RATE IN TURNING OF AISI D3 STEEL BY VARYING FLOW RATE OF COOLANT

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ABSTRACT
In the machining of high carbon steel for a higher metal removal rate it is necessary to operate the machine with high speed, high feed, and high depth. The problem of high cutting temperatures and cutting forces makes it necessary to use large amounts of cutting fluids. Coolants are mainly used to reduce friction in the machining area i.e., the tool and the workpiece perform two major functions namely for cooling, and lubrication, and also for higher metal removal rate supplying of cutting fluid place vital role. In this work, we used the soluble oil which was supplied with different flow rates while machining AISI D3 high carbon steel and tungsten carbide tip as a cutting tool. Taguchi L27 orthogonal array with 3 levels and 4 factors 27 experimental runs have been used and Analysis of variance (ANOVA) has been used for the highest percentage of contribution of process parameter. After performing all the experiments, the optimal result of the metal removal rate (MRR) obtained is 4gm/sec. At a speed of 1500 rpm, feed of 0.347mm/rev, depth of cut of 1 mm, and flow rate of 0.038l/sec.

Keywords: Coolant, High carbon steel AISI D3, Turning operation, Flow rate, Taguchi L27 orthogonal array, S/N ratio, ANOVA.

Introduction:
Taguchi Optimization technique is used to avoid the problem of improper selection of process parameters. By using different optimization techniques, the process parameters are selected. Taguchi's parametric design is a tool for robust design to eliminate some problems like high manufacturing costs, low product quality, etc. Taguchi has anticipated a method by conducting the experiments with good guidelines [1-7]. In this method, a set of orthogonal arrays are used. These orthogonal arrays are used for doing a minimal number of experiments and it gives the total information about the performance parameters and the design of the experiment with levels obtained.

AISI (American Iron and Steel Institute) D3 steel is one of the alloys of steel. After heat treatment, this steel gets the properties like high absorption/wear resistance, good dimensional stability, and high compression strength. It allows corrosion resistance when it is polished. This steel is belonged to the 'D' group based on the AISI classification system [8]. AISI D3 steel shows high wear resistance when it contains 12% of chromium tool steel. D3 steel offers better surface conditions under oil hardening. Mostly used for Cold die punches, Ejector pins, Die drawings, Power metal tooling, Blanking dies for paper, and Shear blades. The condition of cutting tools plays an important role in hard machining. Turning is the machining process used to machine cylindrical objects to desired dimensions [9-18]. The main aim of the industry is to produce quality products at a low cost in the required dimensions. Turning operations are performed on lathe machines. In turning, the workpiece is fixed in the machine and rotated at a high speed. During this process, the cutting parameters highly depend upon the workpiece, cutting tool, material, etc. Cutting fluids play a vital role in machining. It reduces wear and improves the quality of a workpiece. There are different types of cutting fluids like water, vegetable oil, soluble oils, mixed oils, synthetic oils, etc [19-28]. In this experiment, different flow rates and input parameters (speed, feed, depth of cut) are taken into consideration. Flow rates play a major role in this experiment. Three different flow rates such as 0.038l/sec, 0.043 l/sec, and 0.050 l/sec have been considered.

Experimental Work

The setup of the lathe machine is another crucial step in ensuring the accuracy and reliability of our turning operation. The first-step is to take the round bar of the workpiece and secure it into the spindle chuck. The required speed and feed rates are then set for the machining process. The process of experimental work is based on the Taguchi technique. In this Taguchi technique, an L27 orthogonal array with four factors and three levels is used for turning operations. The metal removal rate is measured before and after machining with their weights.

MRR= (before weight - after weight) / time

Fig 1: Machining with nozzle for varying flow rates

Fig 2: Weight measurement

Table 1: L27 Orthogonal array with MRR values

Exp. No	Speed (rpm)	Feed (mm/rev)	Depth (mm)	Flow Rate (liters/sec)	MRR (gm/sec)
1	635	0. 285	0.5	0.04	0.36
2	635	0. 285	0.75	0.04	0.77
3	635	0. 285	1	0.05	1.71
4	635	0.35	0.5	0.04	0.75
5	635	0.35	0.75	0.05	1
6	635	0.35	1	0.04	1.28
7	635	0.5	0.5	0.05	1
8	635	0.5	0.75	0.04	1.25
9	635	0.5	1	0.04	2.2
10	975	0. 285	0.5	0.04	0.8
11	975	0. 285	0.75	0.04	1.25
12	975	0. 285	1	0.05	1.4
13	975	0.35	0.5	0.04	0.5
14	975	0.35	0.75	0.05	1.3
15	975	0.35	1	0.04	1.75
16	975	0.5	0.5	0.05	1.66
17	975	0.5	0.75	0.04	1.5
18	975	0.5	1	0.04	3
19	1500	0. 285	0.5	0.04	1.33
20	1500	0. 285	0.75	0.04	2
21	1500	0. 285	1	0.05	2.5
22	1500	0.35	0.5	0.04	1.66
23	1500	0.35	0.75	0.05	2
24	1500	0.35	1	0.04	4
25	1500	0.5	0.5	0.05	2
26	1500	0.5	0.75	0.04	1.5
27	1500	0.5	1	0.04	3

RESULTS AND DISCUSSION

Using MINITAB software, the S/N ratio values of AISI D3 high-carbon steel are calculated. Taguchi with L27 Orthogonal array design with four factors and three levels, twenty-seven experiments are considered for metal removal rate values to calculate better S/N ratio values by using Larger is the better formula.

Table 2: S/N ratio values

Level	speed	feed	depth of cut	flow rate
1	0.22	1.43	-0.2	1.37
2	1.59	1.79	2.57	3.06
3	6.45	5.04	5.91	3.83
Delta	6.23	3.6	6.13	2.46
Rank	1	3	2	4

Table 3: Response table for means

Level	speed	feed	depth of cut	flow rate
1	1.15	1.35	1.12	1.42
2	1.35	1.47	1.4	1.68
3	2.22	1.9	2.2	1.62
Delta	1.07	0.55	1.09	0.26
Rank	2	3	1	4

Table 4: Analysis of Variance for S/N Ratios

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Speed	2	233	193	96.3	12.9	0
Feed	2	107	71.1	35.5	4.76	0.02
Depth of cut	2	170	170	84.8	11.4	0.01
Flow rate	2	38.5	28.2	14.2	1.91	0.18
Error	18	48.4	135	7.46		
Total	26	596				

In the MINITAB software by selecting the stat some options are viewed in the stat, next select the DOE and next select the create Taguchi design. A table is shown as Taguchi design representing levels, factors, display available design, design, factors, options and ok. According to analyze L27 orthogonal array select 3 levels 4 factors, L-27 (2-13) in available design, L27 runs in design, entering the speed, feed, depth of cut, flow rate in given A, B, C, D, and their values in next column and select ok to get 27 designs.

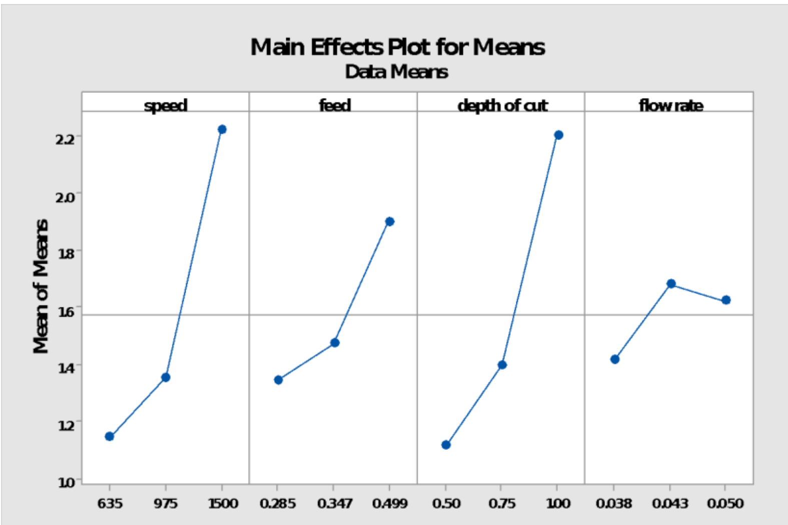
Table 5: Signal to noise (S/N) ratio values

Exp. No	**Speed (RPM)**	**Feed**	**Depth of Cut (mm)**	**Flow Rate (l/sec)**	**MRR (gm/sec)**	S/N
1	635	0. 285	0.5	0.04	0.36	-8.87
2	635	0. 285	1	0.04	0.77	-2.27
3	635	0. 285	1.5	0.05	1.71	4.66
4	635	0.347	0.5	0.04	0.75	-2.5
5	635	0.347	1	0.05	1	0
6	635	0.347	1.5	0.04	1.28	2.14
7	635	0.499	0.5	0.05	1	0
8	635	0.499	1	0.04	1.25	1.94
9	635	0.499	1.5	0.04	2.2	6.85
10	975	0. 28	0.5	0.04	0.8	-1.93
11	975	0. 28	1	0.04	1.25	1.93
12	975	0. 285	1.5	0.05	1.4	2.92
13	975	0.347	0.5	0.04	0.5	-6.02
14	975	0.347	1	0.05	1.3	2.48
15	975	0.347	1.5	0.04	1.75	-2.5
16	975	0.499	0.5	0.05	1.66	4.4
17	975	0.499	1	0.04	1.5	3.52
18	975	0.499	1.5	0.04	3	9.54
19	1500	0. 285	0.5	0.04	1.33	2.48
20	1500	0. 285	1	0.04	2	6.02
21	1500	0. 285	1.5	0.05	2.5	7.96
22	1500	0.347	0.5	0.04	1.66	4.4
23	1500	0.347	1	0.05	2	6.02
24	1500	0.347	1.5	0.04	4	12
25	1500	0.499	0.5	0.05	2	6.02
26	1500	0.499	1	0.04	1.5	3.52
27	1500	0.499	1.5	0.04	3	9.54

Using the L27 designs to perform the experiments and MRR values has been calculated. Enter the MRR values in the next column as shown in the figure. Again, select stat, DOE, Taguchi, analyze Taguchi, and analyze Taguchi design box is obtained with C5 MRR, select, graphs, analysis, terms, options, storage, ok. Select the C5 MRR option and click the select option it reads the value and enters it in the bedside box, then go to the graphs option and select signal-to-noise-ratio and means, in analysis, option select display response tables for signal-to-noise ratio and means and select a fit linear model for the signal to noise ratio, in options select larger the better and click ok. The S/N ratios, means graphs and tables are displayed and values of S/N ratios are displayed in the worksheet table. From the analysis of variance values, this experiment got probability values below 0.005, an error of below 9%.

Graph 1: Main effects of S/N ratios

Generally, signal-to-noise ratio values must be close to zero. So, from the above S/N graph larger the better, we conclude that speed of 1500, the optimum value occurs at a value of 6.7, So the optimum value of speed is A. Now at the depth of cut 1, the optimum parameter occurs at a value of 5.8 so, the optimum value depth of cut is B. Now at the feed 0.499, the optimum parameter occurs at a value of 5.1 so, the optimum value feed is C. Now at the flow rate of 0.050, the optimum parameter occurs at a value of 3.8. So, the optimum value of the flow rate is D.



Graph 2: Main effects of means

The mean values must be close to zero. So, from the above mean graph larger the better, we conclude that speed of 1500, the optimum value occurs at a value of 2.24 so the optimum value of speed is A. Now at the depth of cut 1, the optimum parameter occurs at a value of 2.2 so, the optimum value depth of cut is B. Now at the feed 0.499, the optimum parameter occurs at a value of 1.95 so, the optimum value feed is C. Now at the flow rate of 0.050, the optimum parameter occurs at a value of 1.7. So, the optimum value of the flow rate is D.

Table 6: Mean Values of MRR

Process parameters	Mean Values of Metal Removal Rate				
	1	2	3	Max-min	Rank
Speed(A)	0.22	1.59	6.45	6.23	1
Feed(B)	1.43	1.79	5.04	3.6	3
depth of Cut(C)	-0.2	2.57	5.91	6.13	2
Flow Rate(D)	1.37	3.06	3.83	2.46	4

Table 7: Optimum levels of metal removal rate

Process Parameters	Optimum Levels for Metal Removal Rate
Speed	A_1
Depth of Cut	B_2
Feed	C_3
Flow Rate	D_4

Analysis of variance (ANOVA)

The ANOVA results are obtained by the Taguchi technique, by finding the metal removal rate values and S/N ratios. The Fisher and Probability values are below the limits. According to the sum of squares, the percentage (%) contribution of the experiment is measured.

Table 8: ANOVA

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	232.7	192.7	96.34	12.91	0.001
Feed	2	107.1	71.09	35.45	4.76	0.022
Depth of cut	2	169.7	169.7	84.83	11.36	0.009
Flow rate	2	38.45	28.25	14.23	1.91	0.178
Error	18	48.36	134.6	7.464		
Total	26	596.2				

From the above ANOVA results, for speed F value is 0.001 which is very less than 0.05, which tells us speed with 39% is the highest significant factor among all.

Percentage contribution:

Speed = 232.68/596.23 =0.39*100 =39 %
Feed = 107.09/596.23 =0.17*100 =17%
Depth of cut = 169.65/596.23 = 0.28*100=28%
Flow rate = 38.45/596.23 =0.064*100 = 6.4%
Error =48.36/596.23 =0.08*100 =8%

CONCLUSIONS

This project is focused on finding the optimum process parameters for a higher metal removal rate by using Taguchi's optimization technique in turning high-carbon steel. The highest metal removal rate of 4gm/sec has been observed at a speed of 1500rpm, feed of 0.347 mm/rev, depth of cut of 1mm, and flow rate of 0.038 l/sec. The highest influence factor is Speed, which influences the metal removal rate of with 39%. Depth of cut is the second influence factor that influences the metal removal rate of 28%. Feed is the third influence factor that influences the metal removal rate of 17%. Flow rate is the fourth influence factor that influences the metal removal rate of 6.4%. The unspecified parameters like vibrations and room temperature, during machining caused an error of 8%.

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