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Productivity Improvement by Cycle Time Reduction in CNC Machining

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Abstract: **The study presents an investigation of turning operation on metals difficult to machine. Hard turning is becoming more popular for machining hardened steels as it has several benefits over grinding. PCBN carbide insert is the dominant tool material for hard turning applications due to its high hardness, high wear resistance, and high thermal stability. The project objective is to establish a correlation between cutting parameters such as cutting speed, feed rate and depth of cut with material removal rate and surface roughness on work piece. The objective is to optimize the process parameters of CNC turning of H-13 based on important technological characteristics. Also the effect of speed, feed and depth of cut individually studied on the final outcome to increase the material removal rate (MRR) and to decrease the tool tip temperature (T) and surface roughness (Ra), mathematical models will be established, relating the performance measures and input parameters by regression analysis. The working ranges of the parameters for subsequent design of experiment, based onTaguchi's L9 Orthogonal Array (OA) designs have been selected. Statistical methods will be used to estimate relation between output parameters and input parameters like ANOVA and regression analysis. Optimization of process parameters will be carried out by using Grey relational analysis (GRA).**

Keywords: ANOVA, GRA, H-13, PCBN, Cutting speed, Feed rate, depth of cut.

I. INTRODUCTION

The materials having high-tensile strength and resistance to wear and impact, which are frequently used in the aerospace and nuclear industries, are generally difficult to machine. High manganese steel is one of these materials. For the machining of high manganese steels, the cutting tool materials must be harder than the workpiece materials. These types of materials can be machined with sintered carbide tools and the speed steels with cobalt. Due to the high cost of changing and sharpening cutting tools, different machining methods are being used. Machining by softening the workpiece is a more effective method than strengthening the cutting tool. It is suggested that these materials should be machined by heating. The heating of the workpiece is not a new method for making easy the properties of the machinability of materials. For machining, it is necessary to choose the best heating method to heat the materials. Selecting the wrong heating method can induce undesirable structural changes in the workpiece and increases the machining cost. In the published works, there are different heating methods described which are used for heating the workpiece. Electrical resistance, plasma arc and other heating methods in hot machining have been used.

II. INTRODUCTION TO TAGUCHI METHOD

Taguchi Method is developed by Dr. Genichi Taguchi, a Japanese quality management consultant. The method explores the concept of quadratic quality loss function (refer Figure A below) and uses a statistical measure of performance called Signal-to-Noise (S/N) ratio. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/process to be optimized.

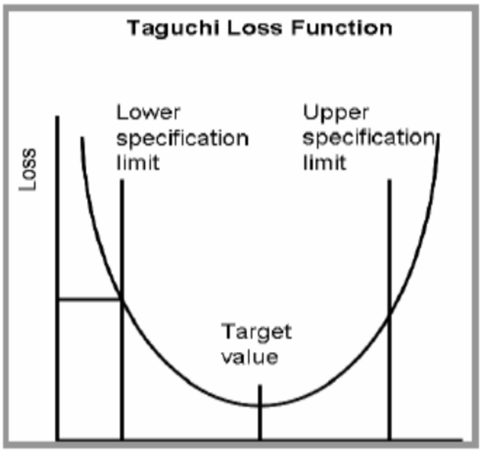


Fig 1. Taguchi's quadratic loss function

III. MATERIAL

H-13 is used extensively in most industry sectors for a wide range of applications. This grade has found wide acceptance for die casting dies for zinc, white metal, aluminum and magnesium. It is also widely used for extrusion dies, trimmer dies, gripper dies, hot shear blades, casings, and other similar hot work applications.Hot die steel (H-13) is an important material for various manufacturing industries mostly because of its high melting point, high degree of hardness and good wear resistance over a wide range of temperatures. It is used for drawing dies, blanking dies, forming dies, bushings, gauges, etc. Even most CNC machine today have process control, but selecting and maintaining optimal setting is still an extremely difficult job which yet to be satisfactorily addressed. The objective is to optimize the process parameters of CNC turning of H-13 based on important technological characteristics.

IV. ORTHOGONAL ARRAY

Since 4 controllable factors and three levels of each factor were considered L9 Orthogonal Array was selected for this study.

V. ANALYSIS OF RESULTS

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) designs have been selected. Statistical methods will be used to estimate relation between output parameters and input parameters like ANOVA and regression analysis. Optimization of process parameters will be carried out by using Grey relational analysis (GRA). This method is chosen because it can perform analysis of more than one factor at a same time while reducing number of experiment which indirectly reduces cost and time in finding optimal parameter.

VI. EXPERIMENTAL

TABLE 1 CHEMICAL COMPOSITION OF H-13

ELEMENT	CONTENT (wt%)
Chromium, Cr	4.75-5.50
Molybdenum, Mo	1.10-1.75
Silicon, Si	0.80-1.20
Vanadium, V	0.80-1.20
Carbon, C	0.32-0.45
Nickel, Ni	03
Copper, Cu	0.25
Manganese, Mn	0.20-0.50
Phosphorus, P	0.03
Sulfur, S	0.03

TABLE 2 MECHANICAL PROPERTIES OF H-13

PROPERTIES	METRIC
Tensile strength, ultimate (@20°C/68°F, varies with heat treatment)	1200 - 1590 MPa
Tensile strength, yield (@20°C/68°F, varies with heat treatment	1000 - 1380 MPa
Reduction of area (@20°C/68°F)	0.5
Modulus of elasticity (@20°C/68°F)	215 GPa
Poisson's ratio	0.27-0.30

VII. EXPERIMENTAL SET UP

The turning operation is carried out in dry environment i.e. without coolant. These experiment were conducted using the hardware listed in Table 3.4 on CNC lathe machine as shown in Photograph 3.1 at Sahayog Engineering, B-43, MIDC, Chikalthana, Aurangabad -431210. A Cylindrical bar of H-13 (length 100 mm, diameter 32 mm) was used as workpiece to carry out experiments on CNC lathe by a PCBN Secomax CBN060K carbide insert as cutting tool without a coolant.

Fig 2. Setup for Hard Turning

TABLE 3 LEVELS AND VALUES OF INPUT PARAMETERS

	1	2	3
Speed (rpm)	1753	1984	2215
Feed (mm/rev)	0.02	0.03	0.04
Depth of cut (mm)	0.7	1.2	1.7

VIII. RESULT ANALYSIS

TABLE 4 CYCLE TIME REDUCTION

Sr. No	Before	After	% reduction
1	1.11	0.56	49.28
2	1.09	0.55	49.84
3	1.11	0.58	47.78
4	1.10	0.56	48.42
5	1.10	0.54	50.07

Before optimizing the process parameters grinding was carried out after turning which consumes extra time. When machine operated with optimum setting it was found that there is 49.07% reduction in cycle time.

TABLE 5 PRODUCTION COST REDUCTION

Sr. No	Before	After	% reduction
1	305.5	240	27.29
2	302	235	28.51
3	307.33	245	25.44
4	301.33	240	25.55
5	299.75	232	29.20

When machine operated with optimum setting it was found that there is 27.12 % reduction in production cost.

TABLE 6 PRODUCTIVITY IMPROVEMENT

Sr. No	Before	After	% reduction
1	8.8	10.71	17.83
2	9.1	10.90	16.51
3	8.8	10.34	14.89
4	8.9	10.71	16.9
5	9.2	10.10	8.9

When machine operated with optimum setting it was found that there is 15% improvement in productivity.

TABLE 7 LAYOUT FOR EXPERIMENTAL DESIGN ACCORDING TO L9 ARRAY

Expt. No.	Speed (RPM)	Feed (mm/rev)	DOC (mm)
1	1753	0.02	0.7
2	1753	0.03	1.2
3	1753	0.04	1.7
4	1984	0.02	1.2
5	1984	0.03	1.7
6	1984	0.04	0.7
7	2215	0.02	1.7
8	2215	0.03	0.7
9	2215	0.04	1.2

TABLE 8 RESULTS FOR S/N RATIO FOR MRR

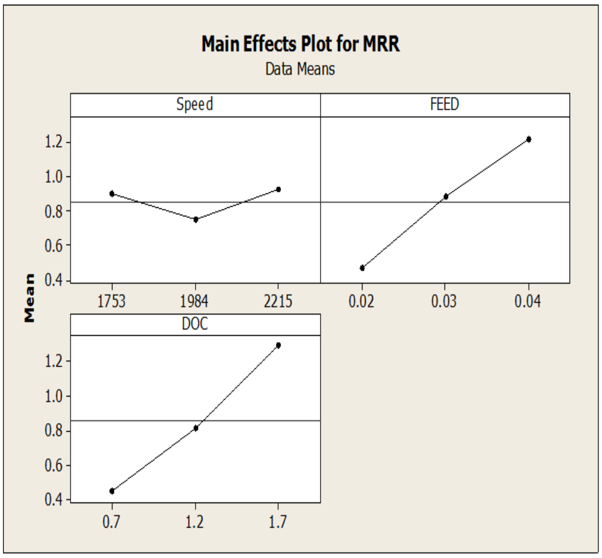
Expt. No.	Speed (RPM)	Feed (mm/rev)	DOC (mm)	S/N Ratio for MRR
1	1753	0.02	0.7	-12.3958
2	1753	0.03	1.2	-2.04746
3	1753	0.04	1.7	4.349679
4	1984	0.02	1.2	-11.3727
5	1984	0.03	1.7	2.542096
6	1984	0.04	0.7	-4.15217
7	2215	0.02	1.7	-0.91515
8	2215	0.03	0.7	-6.0206
9	2215	0.04	1.2	2.734411

TABLE 9 RESULTS FOR S/N RATIO FOR %RTTT

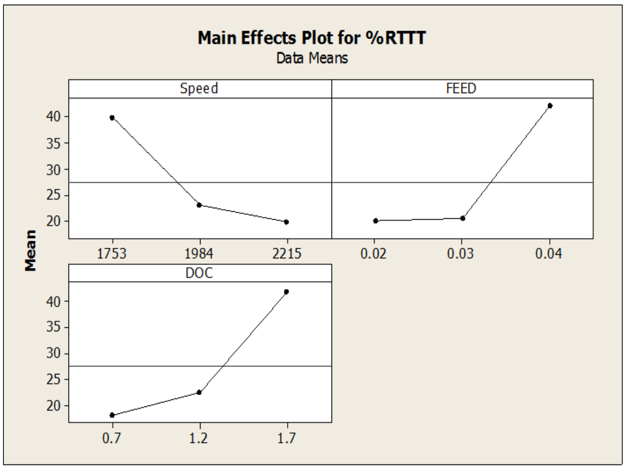
Expt. No.	Speed (RPM)	Feed (mm/rev)	DOC (mm)	S/N Ratio for %RTTT
1	1753	0.02	0.7	-26.1926
2	1753	0.03	1.2	-27.321
3	1753	0.04	1.7	-37.614
4	1984	0.02	1.2	-24.8309
5	1984	0.03	1.7	-28.8308
6	1984	0.04	0.7	-27.5388
7	2215	0.02	1.7	-26.8247
8	2215	0.03	0.7	-20.206
9	2215	0.04	1.2	-28.5074

TABLE 10 RESULTS FOR S/N RATIO FOR RA (µM)

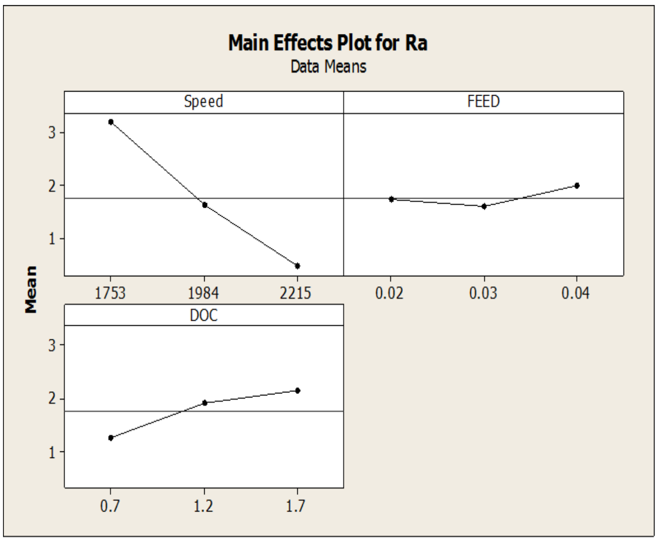
Expt. No.	Speed (RPM)	Feed (mm/rev)	DOC (mm)	S/N Ratio for Ra (µm)
1	1753	0.02	0.7	-0.54699
2	1753	0.03	1.2	-4.16345
3	1753	0.04	1.7	-6.52672
4	1984	0.02	1.2	-0.70859
5	1984	0.03	1.7	3.655305
6	1984	0.04	0.7	3.036218
7	2215	0.02	1.7	7.081734
8	2215	0.03	0.7	19.17215
9	2215	0.04	1.2	15.75625



Graph 1. Main effect plot for MRR



Graph 2. Main effect plot for %RTTT



Graph 3. Main effect plot for Ra (µm)

TABLE 11 NORMALIZATION

EXPT. NO.	NORMALIZATION		
	MRR	%RTT	Ra
1	0.0000	0.8455	0.555263
2	0.3901	0.8024	0.265789
3	1.0000	0.0000	0
4	0.0213	0.8905	0.544737
5	0.7801	0.7353	0.770263
6	0.2695	0.7934	0.744737
7	0.4681	0.8220	0.882895
8	0.1844	1.0000	1
9	0.8014	0.7507	0.947368

TABLE 12 DEVIATION SEQUENCE

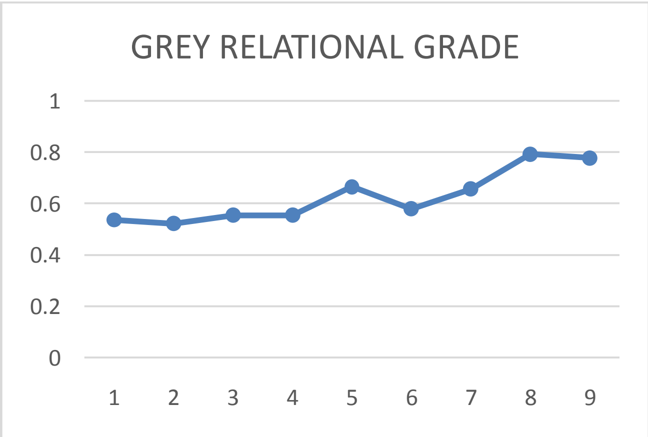
EXPT. No	DEVIATION SEQUENCE		
	MRR	%RTTT	Ra
1	1.0000	0.1545	0.444737
2	0.6099	0.1976	0.734211
3	0.0000	1.0000	1
4	0.9787	0.1095	0.455263
5	0.2199	0.2647	0.229737
6	0.7305	0.2066	0.255263
7	0.5319	0.1780	0.117105
8	0.8156	0.0000	0
9	0.1986	0.2493	0.052632

TABLE 13 GREY RELATIONAL COEFFICIENT

EXPT. No	GREY RELATIONAL COEFFICIENT		
	MRR	%RTTT	Ra
1	0.3333	0.7639	0.529248
2	0.4505	0.7167	0.405117
3	1.0000	0.3333	0.333333
4	0.3381	0.8203	0.523416
5	0.6946	0.6539	0.685179
6	0.4063	0.7076	0.662021
7	0.4845	0.7375	0.810235
8	0.3801	1.0000	1
9	0.7157	0.6673	0.904762

TABLE 14 GREY RELATIONAL GRADE

EXPT. No	PROCESS PARAMETERS			GRG
	Speed	FEED	DOC	
1	1	1	1	0.542156
2	1	2	2	0.524114
3	1	3	3	0.555556
4	2	1	2	0.56062
5	2	2	3	0.677876
6	2	3	1	0.592001
7	3	1	3	0.677421
8	3	2	1	0.793351
9	3	3	2	0.762591



Graph 4. Scatter plot of GRG vs order of experiment

IX. CONFIRMATION TEST

TABLE 15 CONFIRMATION RESULTS

	Predicted	Experimental	% Error
MRR (Gram/sec)	0.49	0.5	2
%RTT (Degree Celsius)	9.55	10.02	4.69
Ra (μm)	0.22	0.23	4.3

X. CONCLUSIONS

In this work, experimental investigation has been reported for CNC turning of H-13 material. An overview of the principle of CNC turning, its experimental set-up and machining process is discussed. The report focuses on optimization of process parameters to improve machine characteristics. Based on the results of the experiments and statistical analysis carried out, the following general conclusions were drawn.

1] In CNC turning it was found that the parameters like speed feed and depth of cut are significant and has strong effect on process characteristics.

2] All individual graphs for Speed, feed and depth of cut from chapter no 4 show increasing trend for MRR. With feed and DOC %RTTT increases bur with increase in speed it decreases. Ra decreases with speed and increases with DOC but with change in feed there is no significant effect.

3] The value of material removal rate (MRR), % rise in tool tip temperature (%RTTT) and surface roughness (Ra) can be predicted by following equations:

MRR	= - 1.21 + 0.000065 Speed + 32.3 Feed + 0.843 DOC
%RTTT	= 58.5 - 0.0439 Speed + 966 Feed + 23.7 DOC
Ra	= 12.1 - 0.00589 Speed + 11.5 Feed + 0.893 DOC

4] Process parameters were optimized for stable machining condition. The optimized values are speed = 2215 rpm, feed = 0.03 mm/rev and DOC = 0.7 mm.

5] Grey relation theory has been found efficient to convert multiple responses into an equivalent single objective function. Thus, a multi-objective optimization problem has been converted into a single objective function optimization problem which can be solved by Taguchi method.

6] The cycle time reduction, production cost reduction and improvement in the productivity

	Before	After	%
Cycle time	1.102	0.56	49.07 reduction
Production cost	303.2	238.4	27.12 reduction
Productivity	8.96	10.55	15 Improvement

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