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RESEARCH ARTICLE

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MULTI OBJECTIVE OPTIMIZATION OF CUTTING PARAMETERS IN TURNING OPERATION BY PCA & TAGUCHI METHOD

GAJANAN KHAIRE*, S.S. SARNOBAT, N.K. KAMBLE
Padmashree Dr. D.y.patil College of engineering, Akurdi, Pune University, Maharashtra, India

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GAJANAN KHAIRE

S.S.SARNOBAT

N.K. Kamble

ABSTRACT

In machining operations, achieving desired surface quality features of the machined product, is really a challenging job. Because, these quality features are highly correlated and are expected to be influenced directly or indirectly by the direct effect of process parameters or their interactive effects (i.e. on process environment). However, the extents of significant influence of the process parameters are different for different responses. Therefore, optimization of surface roughness is a multi-factor, multi-objective optimization problem. Therefore, to solve such a multi-objective optimization problem, it is felt necessary to identify the optimal parametric combination, following which all objectives could be optimized simultaneously. In this context, it is essential to convert all the objective functions into an equivalent single objective function or overall representative function to meet desired multi-quality features of the machined surface.

The required multi-quality features may or may not be conflicting in nature. The representative single objective function, thus calculated, would be optimized finally. In the present work, Design of Experiment (DOE) with Taguchi L9 Orthogonal Array (OA) has been explored to produce 9 specimens on copper bard by straight turning operation. Collected data related to surface roughness have been utilized for optimization. Principal Component Analysis (PCA) has been applied to eliminate correlation among the responses and to evaluate independent or uncorrelated quality indices called principal components. Based on quality loss of individual principal components with respect to the ideal condition, CQL (COMBINED QUALITY LOSS) has been calculated to serve as the single objective function for optimization. Finally, Taguchi method has been adopted for searching optimal process condition to yield desired surface quality. Result of the aforesaid optimization procedure has been verified through confirmatory test. The study illustrates the detailed methodology of PCA based Taguchi method and its effectiveness for multi-response surface quality optimization in turning operation.

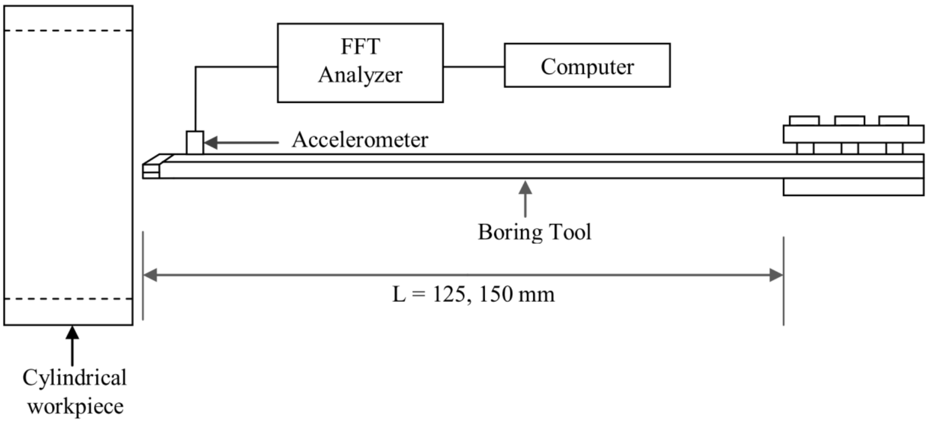
Keywords – Turning operation, PCA, Taguchi method

INTRODUCTION

For conducting any successful experiment, there is a requirement of rigorous planning and background study of the subject. From the understanding of basics of manufacturing and literature review of past and present research, a problem is clearly defined. From the problem definition, it is observed that, vibration created due to large overhang and smaller cross-section of the boring bar the surface finish obtained after machining is poor. The today's industry requirement is to achieve good surface finish to meet the customers' quality requirements. It is planned to use a passive technique of vibration isolation so that much cost will not be involved.

The following sections of the chapter will explain the procedure of planning and conduction of experiments.

Following section of this chapter discuss about the experimental setup and tools used for conducting the experiments.



CNC MACHINE

To eliminate the inherent vibrations of the general purpose lathe machine, the boring operations were carried out on the rigidly mounted and regularly maintained and reliable CNC turning centre of ACE make. The machine specifications are given below.

Plate 1 : ACE JOBBER XL Horizontal Lathe

- Maximum Turning Diameter - 270 mm
- Maximum Turning Length - 400 mm
- Chuck Size - 165 mm
- Spindles - 1
- Motor Power - 3.5 kw
- Spindle Speed - 1440 rpm

BORING BAR

WIDAX S20R STUNL 16F3

Boring bar of 20 mm × 20 mm cross-section and 200 mm long of WIDAX make is used.

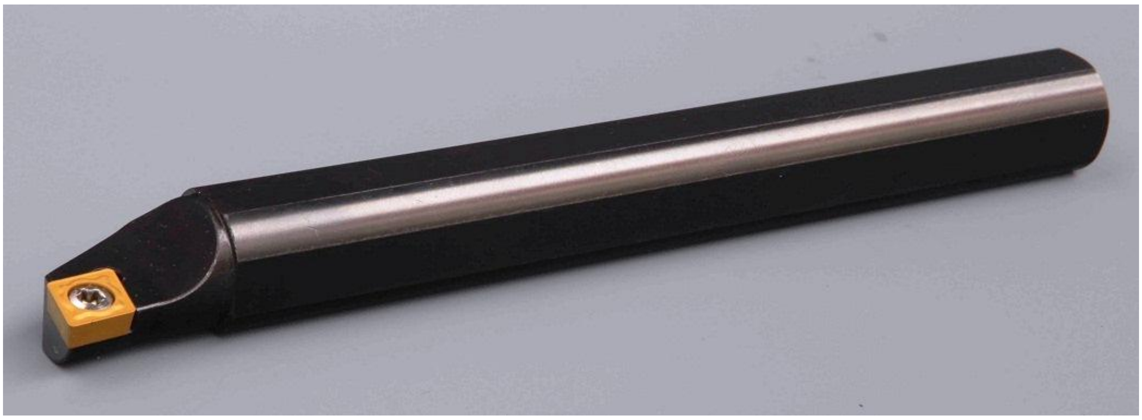
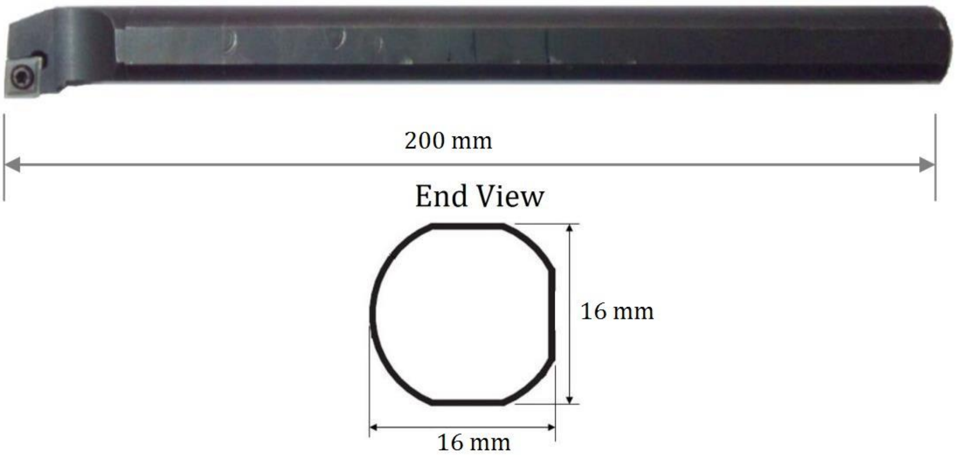


Plate 2 : Standard Boring Bar (WIDAX Make)



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Cermets are cemented carbides, in which titanium carbonitride (TiCN) is used to provide the majority of the hardness instead of tungsten carbide, and a compound of nickel and cobalt serves as the binder. This difference in composition makes the cermets more heat resistant, on the one hand. On the other hand, it diminishes the material's toughness. This type includes composite titanium carbide and titanium nitride–based materials designed for light roughing for high speed finishing in turning, boring, and milling operations. These grades show excellent results on steels, stainless steels, cast irons, and aluminum. They are capable of running at moderate to high speeds and are best used with light feeds and depths of cut. They feature excellent abrasion resistance and thermal properties, as well as lubricity for crater resistance.

WORKPIECE

EN 32 is used as workpiece (25 nos.) material for conducting the experiments.

Plate 4: Unfinished work-pieces

Plate 5 Semi-finished (made true) work-pieces

Case Hardening	Blank carburise EN32 at a temperature between 880-930°C. Refine at temperature of 970-900°C, cool in air, oil or water.
Hardening	Harden at a temperature of 760-780°C. Quench in water.
Tempering	Tempering is recommended for stress relief and maximum case toughness. Tempering range from 150-200°C.

Analysis	Carbon	0.10-0.18%	Phosphorous	0.05% max
	Manganese	0.60-1.00%	Sulphur	0.05% max
	Silicon	0.05-0.35%		

Typical Mechanical Properties*

Tensile Strength N/mm²	Elongation %	Impact Izod J	Impact KCV J
430	18	39	35

(*blank case hardened - 29mm test piece)

(For Test certificate please refer Appendix)
SURFACE ROUGHNESS TESTER
MITUTOYO SJ 201-P (Specifications)

Drive Unit

- Drive Speed - Measuring: 0.25 mm/s and Returning: 0.8 mm/s
- Evaluation Length - 12.5 mm
- Mass - 190 gm

Detector Provided

- Detecting Method - Differential Inductance
- Measuring Range - 350 µm (-200 µm to + 150 µm)
- Material of Stylus - Diamond

- Radius of Skid Curvature - 40 mm
- Mass - 18 gm
- Stylus Tip Radius - 5 µm
- Measuring Force - 4 mN

Display Unit

- Assessed Profile - Primary Profile (P), Roughness Profile (R), DIN 4776 Profile
- Roughness Parameter - Ra, Ry, Rz, Rq, S, Sm, Pc, R3z, mr, Rt, Rpk, Rvk, Mr1, Mr2, A1, A2, Vo
- Roughness Standard - JIS, DIN, ISO, ANSI
- Sampling Length - 0.25 mm, 0.8 mm, 2.5 mm
- Number of Sampling Spans - x1, x3, x5, xL*1
- Digital Filter - 2CR-75%, PC-75%, PC-50%
- Resolution / Range - Auto
- G0 / NO-GO Judgment - UL and LL Limit Values can be Specified
- Power Supply - Via AC Adapter
- Rechargeable Battery - Charging Time 12 hrs (500 measurements)
- Data Output - Via RS 232 interface Unit
- Mass - 290 gm

FFT Analyzer

The accelerometer is attached to the vibration meter of make OROS. The vibration meter, OR34-2, 4 channels, shown in Fig. 6 displays the displacement and acceleration at the free end of the boring tool in the required format.

Plate 6:

The instrument is intended to general acoustic and vibration measurements, environmental monitoring, occupational health and safety monitoring. OR34 provides significant number of results like RMS, PEAK in case of vibration measurements. Results can be viewed in real time or can be saved for further analysis using NVGate application provided with the instrument. Features of OR34 – 2, 4 channels compact analyzer include

- AC/DC power supply
- Real-time bandwidth 40 kHz
- 2 external triggers/tachometers inputs

Accelerometer

Dytran make 3056 B2 D accelerometer is used to measure displacement near the free end of the boring tool.

Figure : Dytran 3056 B2 D accelerometer

The Model 3056 B2 shown in Fig. 4.5 is a magnetic mount accelerometer. Accelerometer is attached to the boring tool at a distance of 40mm from tool tip. Features of Dytran 3056 B2 D accelerometer are;

- Weight, 10 grams
- Material, base, cap & connector titanium
- Operating range, -55 to +120°C
- Frequency range, 1 to 10,000 Hz
- Sensitivity, 100mV/g

TEST MATRIX

Sr. No.	Parameter		Level		
			Low (1)	Medium (2)	High(3)
1	Spindle Speed - N (rpm)	A	100	150	200
2	Feed Rate - f (mm/rev)	B	0.01	0.02	0.03
3	Depth of Cut – t (mm)	C	1	1.5	2

Table 1: L9 Orthogonal Array

Test No.	A	B	C
T1	1	1	1
T2	1	2	2
T3	1	3	3
T4	2	1	2
T5	2	2	3
T6	2	3	1
T7	3	1	3
T8	3	2	1
T9	3	3	2

Run No. 1 as given in Table of Orthogonal Array states that;
A1 = Spindle Speed = 100 rpm
B1 = Feed Rate = 0.02 mm/rev

C1 = Depth of Cut = 1 mm

Similarly one can identify the remaining 8 runs.

EXPERIMENTAL ANALYSIS

INTRODUCTION

Material Removal Rate (MRR)

$$MRR \approx k \times V \times f_r \times t$$

Where,

k is a constant to "correct" speed (V) and part diameter (D) units

V given in surface feet per minute (SFPM), D in inches: k = 12

V given in meters per second (MPS), D in mm: k = 60000

V given in meters per minute (MPM), D in mm: k = 1000

V is desired cutting speed,

D is largest part diameter (initial size)

f_r is machine feed rate units/revolution

t is Depth of cut (inch or mm)

RESULT TABLE

Table 2: Result Table

	Surface Roughness (µm)		**Vibration Level (Acceleration) m/sec^2**		**Material Removal Rate m^3/min**
Test No.	**Y1**	**Y2**	**Y1**	**Y1**	**Y2**
T1	4.25	4.18	1.68×10^{-3}	1.67×10^{-3}	0.4395
T2	4.89	5.01	1.67×10^{-3}	1.68×10^{-3}	3.762
T3	4.11	4.05	1.87×10^{-3}	1.78×10^{-3}	4.0128
T4	5.32	5.37	2.07×10^{-3}	2.11×10^{-3}	1.758
T5	3.78	3.72	6.243×10^{-4}	6.34×10^{-4}	2.0064
T6	2.87	2.68	2.183×10^{-4}	2.024×10^{-4}	1.881
T7	5.67	5.45	4.687×10^{-3}	4.786×10^{-3}	4.2192
T8	4.09	4.12	1.867×10^{-3}	1.768×10^{-3}	1.254
T9	3.45	3.38	2.283×10^{-4}	2.176×10^{-4}	1.254

Test No.	**S/N Ratio**		
	Surface Roughness	**Vibration Level**	**Material Removal**
T1	-12.4963	55.5197	-7.1408
T2	-13.8927	55.5197	11.5084
T3	-12.2134	54.7721	12.0690
T4	-14.5590	53.5967	4.9004
T5	-11.4809	64.0247	6.0484
T6	-8.8703	73.5350	5.4878
T7	-14.9032	46.4904	12.5046
T8	-12.2663	54.8073	1.9660

T9	-10.6683	73.0334	1.9660

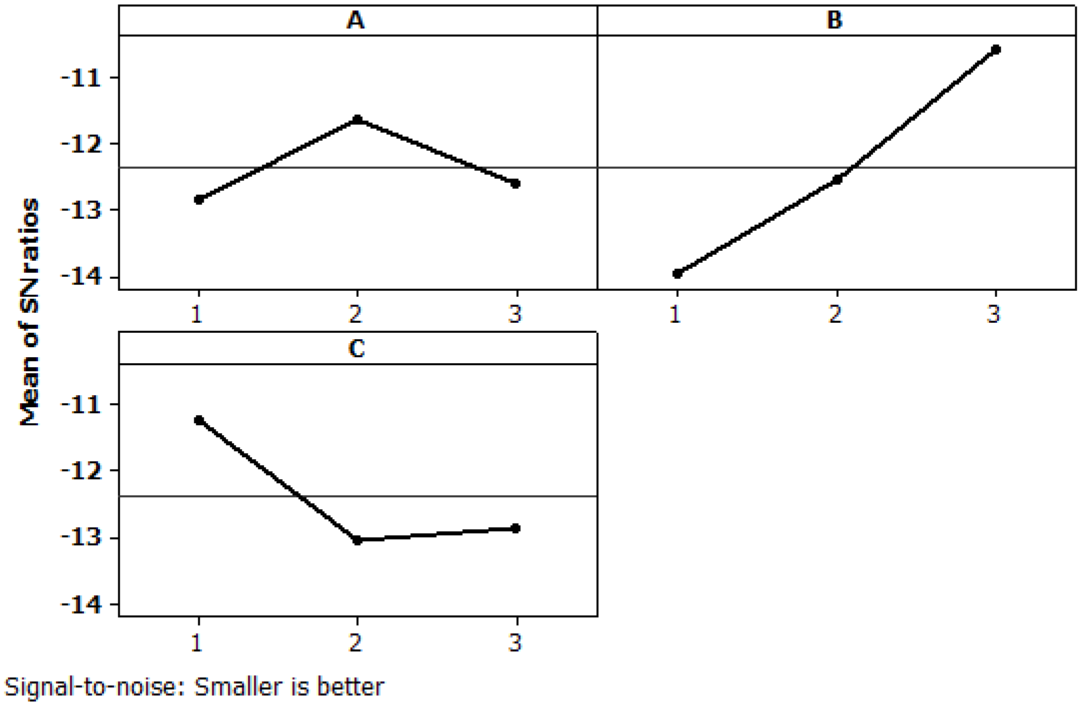


Figure: S/N Ratio for Surface Roughness

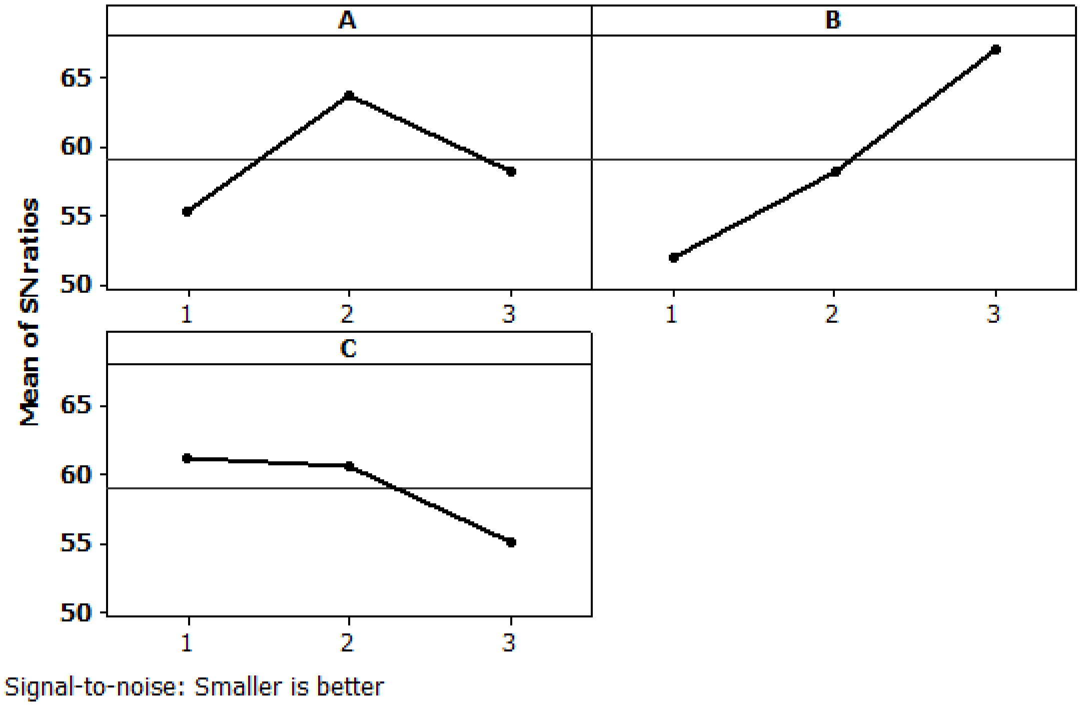


Figure: S/N Ratio for Vibration Level

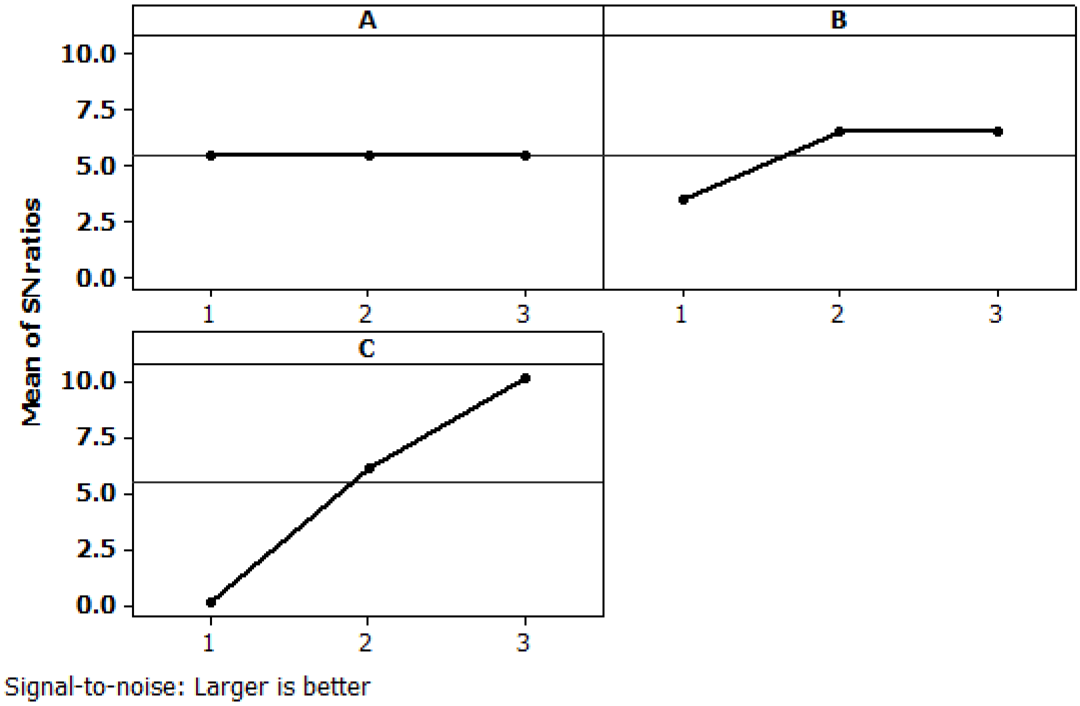


Figure: S/N Ratio for Material Removal Rate

Table 3: Full Factorial Results

Test No.	Surface Roughness (µm)		Vibration Level (Acceleration) m/sec^2		Material Removal Rate (m^3/min)	
	Mean	S/N	Mean	S/N	Mean	S/N
1	4.66556	-13.3201	0.0024861	50.3603	1.49363	-1.9531
2	5.53722	-15.1491	0.0025812	49.7896	2.56013	4.0675
3	5.43056	-14.9749	0.0036487	44.1687	3.71493	8.1499
4	3.89389	-11.8805	0.0010262	56.6086	1.69553	1.1330
5	4.76556	-13.7096	0.0011212	56.0379	2.76203	7.1536
6	4.65889	-13.5354	0.0021888	50.4170	3.91683	11.2360
7	3.04889	-9.9179	0.0004051	65.6049	1.73733	1.1330
8	3.92056	-11.7470	0.0005001	65.0341	2.80383	7.1536
9	3.81389	-11.5728	0.0015677	59.4133	3.95863	11.2360
10	4.20722	-12.0893	0.0017376	58.8086	0.63733	-1.9531
11	5.07889	-13.9184	0.0018327	58.2378	1.70383	4.0675
12	4.97222	-13.7442	0.0029002	52.6170	2.85863	8.1499
13	3.43556	-10.6498	0.0002777	65.0569	0.83923	1.1330
14	4.30722	-12.4789	0.0003727	64.4861	1.90573	7.1536
15	4.20056	-12.3047	0.0014403	58.8653	3.06053	11.2360
16	2.59056	-8.6872	0.0003434	74.0531	0.88103	1.1330
17	3.46222	-10.5162	0.0002484	73.4824	1.94753	7.1536
18	3.35556	-10.3421	0.0008192	67.8616	3.10233	11.2360

19	4.61056	-13.0652	0.0030201	53.2002	0.99793	-1.9531
20	5.48222	-14.8942	0.0031151	52.6294	2.06443	4.0675
21	5.37556	-14.7200	0.0041827	47.0086	3.21923	8.1499
22	3.83889	-11.6257	0.0015602	59.4485	1.19983	1.1330
23	4.71056	-13.4547	0.0016552	58.8777	2.26633	7.1536
24	4.60389	-13.2805	0.0027228	53.2569	3.42113	11.2360
25	2.99389	-9.6630	0.0009390	68.4447	1.24163	1.1330
26	3.86556	-11.4921	0.0010341	67.8740	2.30813	7.1536
27	3.75889	-11.3179	0.0021016	62.2531	3.46293	11.2360

Multi-objective optimization (also known as multi-objective programming, vector optimization, multi-criteria optimization, multi-attribute optimization or Pareto optimization) is an area of multiple criteria decision making, that is concerned with mathematical optimization problems involving more than one objective function to be optimized simultaneously. Multi-objective optimization has been applied in many fields of science, including engineering, economics and logistics (see the section on applications for examples) where optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives. Minimizing weight while maximizing the strength of a particular component, and maximizing performance whilst minimizing fuel consumption and emission of pollutants of a vehicle are examples of multi-objective optimization problems involving two and three objectives, respectively.

Following are the different methods used for multi-response optimization:

1. Genetic Algorithm (GA)
2. Neural Network (NN)
3. Evolutionary Algorithm (EA)
4. Principle Component Analysis (PCA)
5. Grey Relational Analysis (GRA) etc.

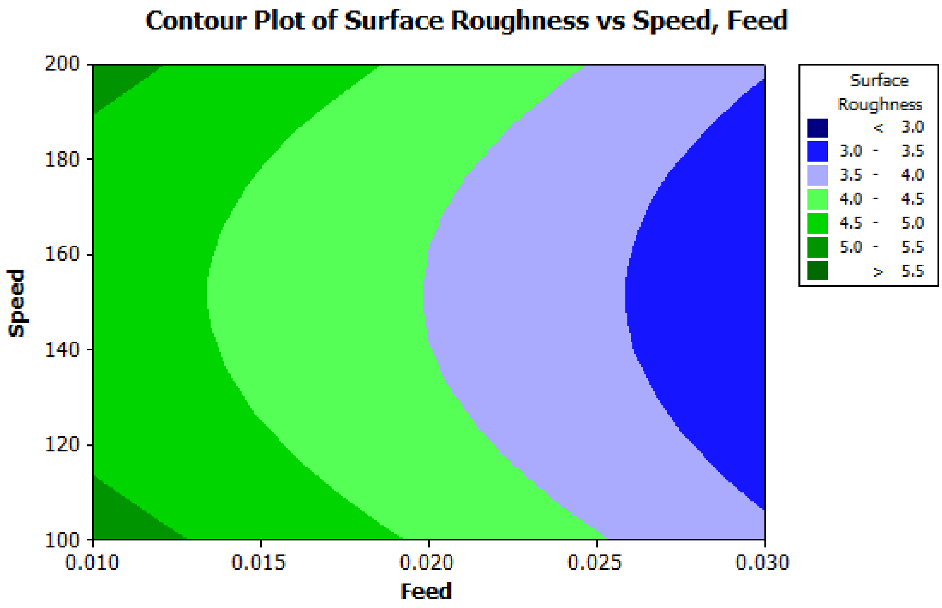
Test No.	**Normalized Response**		
	Surface Roughness (μm)	**Vibration Level (Acceleration) m/sec^2**	**Material Removal Rate (m^3/min)**
1	0.295812886	0.431233002	0.257820733
2	0	0.407060977	0.578929937
3	0.036196914	0.135729355	0.926625117
4	0.557692438	0.802302824	0.318610183
5	0.261876158	0.778156216	0.639719387
6	0.298076466	0.506799176	0.987414567
7	0.844457793	0.960170805	0.331195616
8	0.548641513	0.936024197	0.65230482
9	0.584841821	0.664667158	1
10	0.451358487	0.621482856	0
11	0.155542207	0.59731083	0.321109204
12	0.191742515	0.325979208	0.668804384
13	0.713234645	0.992552678	0.06078945
14	0.417421759	0.96840607	0.381898654
15	0.453618673	0.69704903	0.729593834
16	1	0.975853392	0.073374883

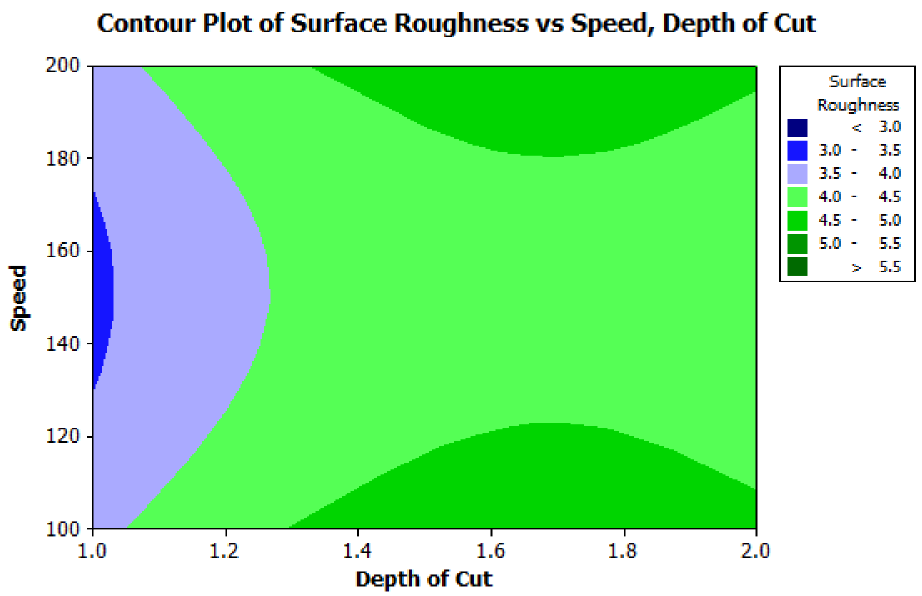
17	0.704187114	1	0.394484088
18	0.740384028	0.854917012	0.742179267
19	0.314478087	0.295503647	0.108571945
20	0.018665201	0.271357039	0.429681149
21	0.054862115	0	0.777376329
22	0.576357639	0.666573469	0.169361395
23	0.280541359	0.642426861	0.490470599
24	0.316741667	0.371069822	0.838165778
25	0.863122993	0.824466868	0.181946828
26	0.567306713	0.800294843	0.503056032
27	0.603507022	0.528963221	0.850751212

Test No.	$\Delta_{0,1}(k)$	$\Delta_{0,2}(k)$	$\Delta_{0,3}(k)$	$\gamma_1(k)$	$\gamma_2(k)$	$\gamma_3(k)$	γ
1	0.704187	0.568767	0.742179	0.415218	0.467829	0.402518	0.428522
2	1	0.592939	0.42107	0.333333	0.457482	0.542847	0.444554
3	0.963803	0.864271	0.073375	0.341576	0.366496	0.87203	0.526701
4	0.442308	0.197697	0.68139	0.530612	0.716643	0.42323	0.556828
5	0.738124	0.221844	0.360281	0.403837	0.69267	0.581205	0.559237
6	0.701924	0.493201	0.012585	0.416	0.503423	0.975448	0.631624
7	0.155542	0.039829	0.668804	0.762727	0.926219	0.427788	0.705578
8	0.451358	0.063976	0.347695	0.525564	0.886563	0.589835	0.667321
9	0.415158	0.335333	0	0.546354	0.598564	1	0.714973
10	0.548642	0.378517	1	0.476807	0.569141	0.333333	0.45976
11	0.844458	0.402689	0.678891	0.371897	0.553901	0.424127	0.449975
12	0.808257	0.674021	0.331196	0.382188	0.425887	0.601543	0.469873
13	0.286765	0.007447	0.939211	0.635513	0.985325	0.347413	0.656084
14	0.582578	0.031594	0.618101	0.46186	0.940567	0.447187	0.616538
15	0.546381	0.302951	0.270406	0.477837	0.622703	0.649008	0.583183
16	0	0.024147	0.926625	1	0.953931	0.350478	0.768136
17	0.295813	0	0.605516	0.628288	1	0.452277	0.693522
18	0.259616	0.145083	0.257821	0.658227	0.775094	0.659786	0.697702
19	0.685522	0.704496	0.891428	0.421755	0.415111	0.359343	0.398736
20	0.981335	0.728643	0.570319	0.337533	0.406953	0.46715	0.403879
21	0.945138	1	0.222624	0.345988	0.333333	0.691923	0.457081
22	0.423642	0.333427	0.830639	0.541335	0.599933	0.375759	0.505676
23	0.719459	0.357573	0.509529	0.410018	0.583041	0.49528	0.496113
24	0.683258	0.62893	0.161834	0.422562	0.442897	0.755476	0.540312
25	0.136877	0.175533	0.818053	0.785081	0.740156	0.379347	0.634861
26	0.432693	0.199705	0.496944	0.536082	0.714587	0.501533	0.584067
27	0.396493	0.471037	0.149249	0.557729	0.514913	0.770121	0.614254

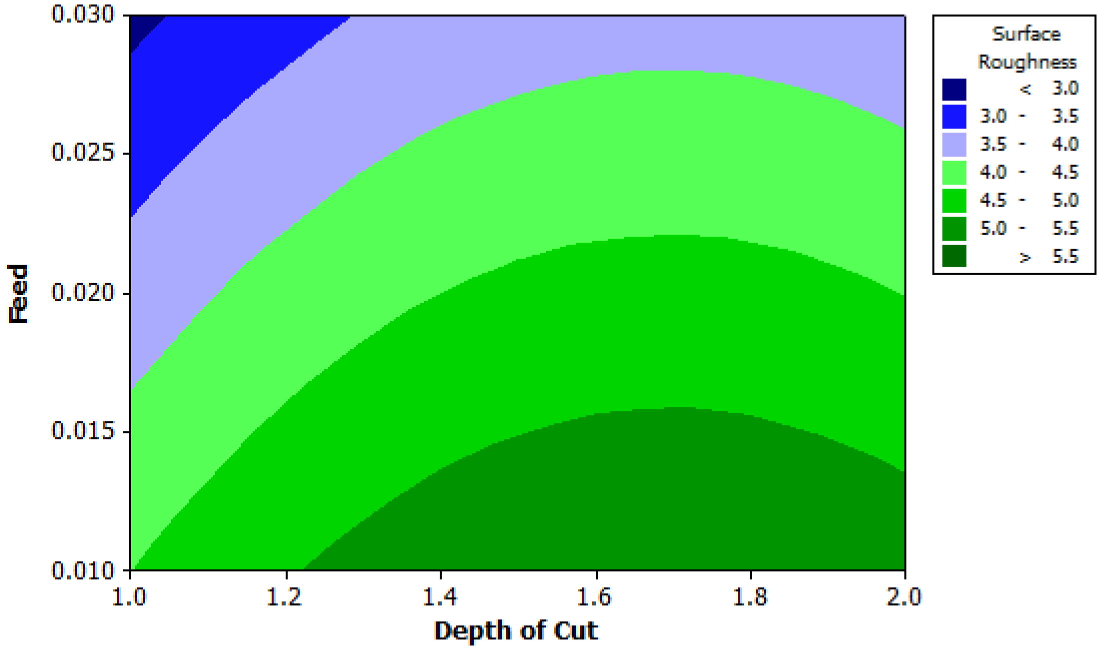
Table 6: Factor and Level Combinations

Sr. No.	Factor		Grey Relational Grade			Max - Min	Rank
			1	2	3		
1	A	Cutting Speed	0.5817	0.5994	0.5149	0.0844	2
2	B	Feed	0.4487	0.5717	0.6756	0.2268	1
3	C	Depth of Cut	0.5682	0.5461	0.5817	0.0356	3

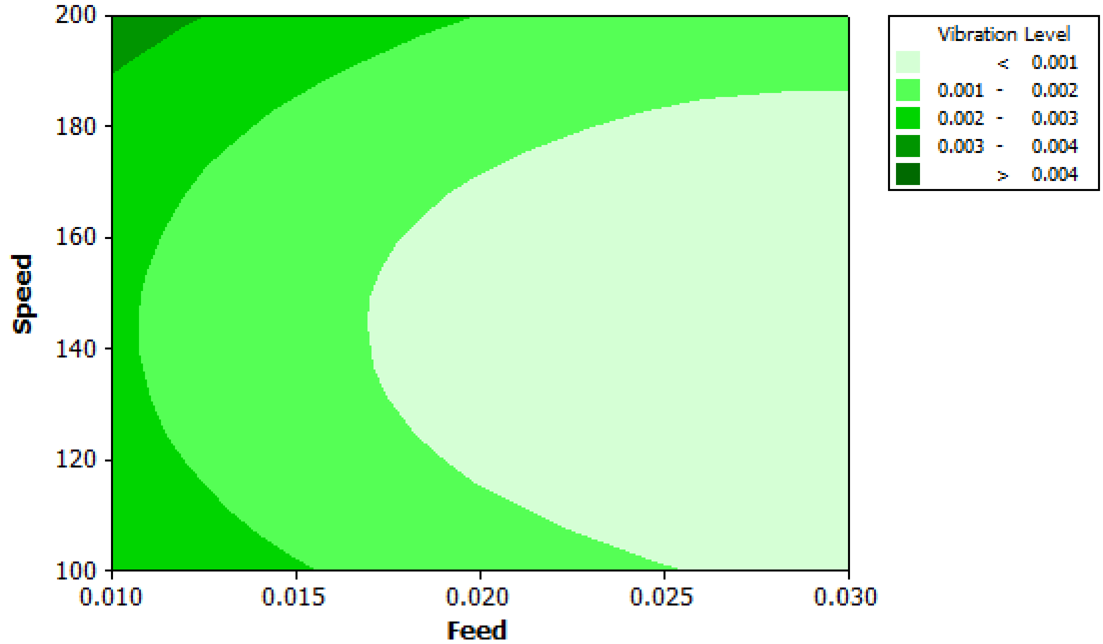


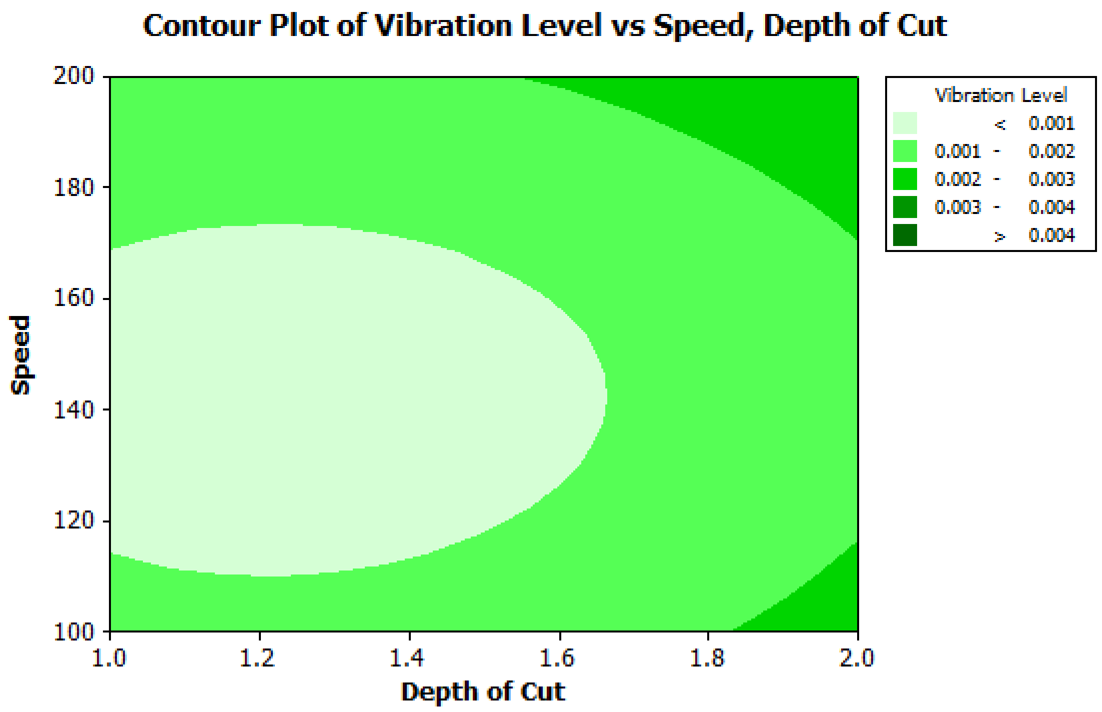


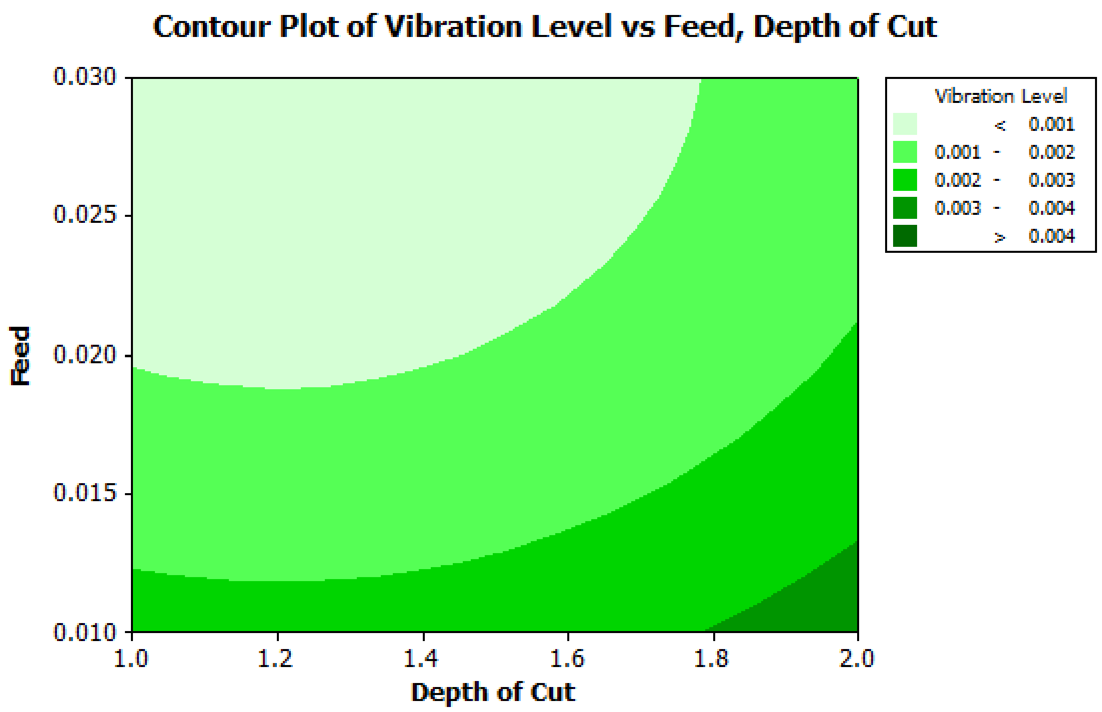
Contour Plot of Surface Roughness vs Feed, Depth of Cut

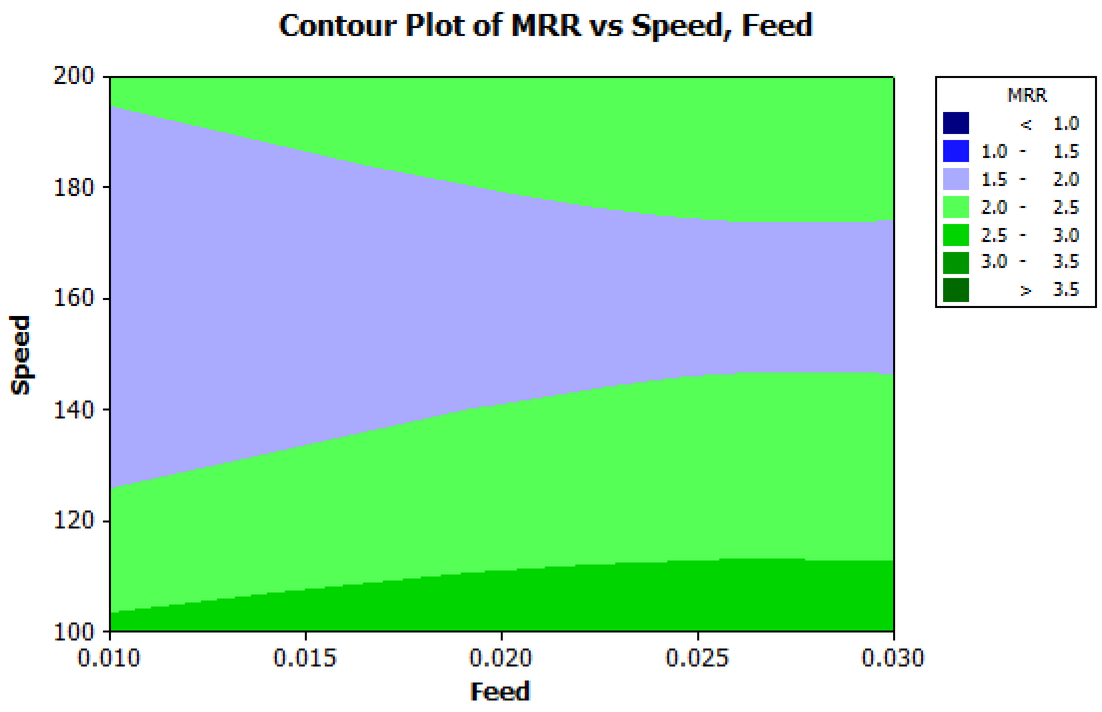


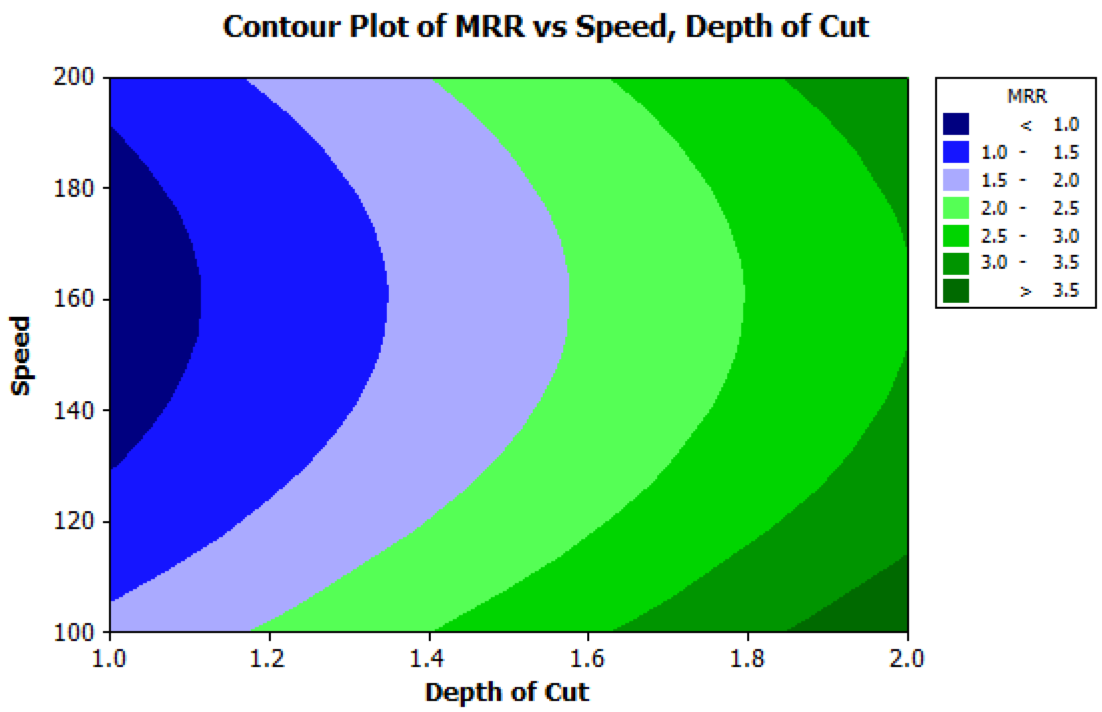
Contour Plot of Vibration Level vs Speed, Feed

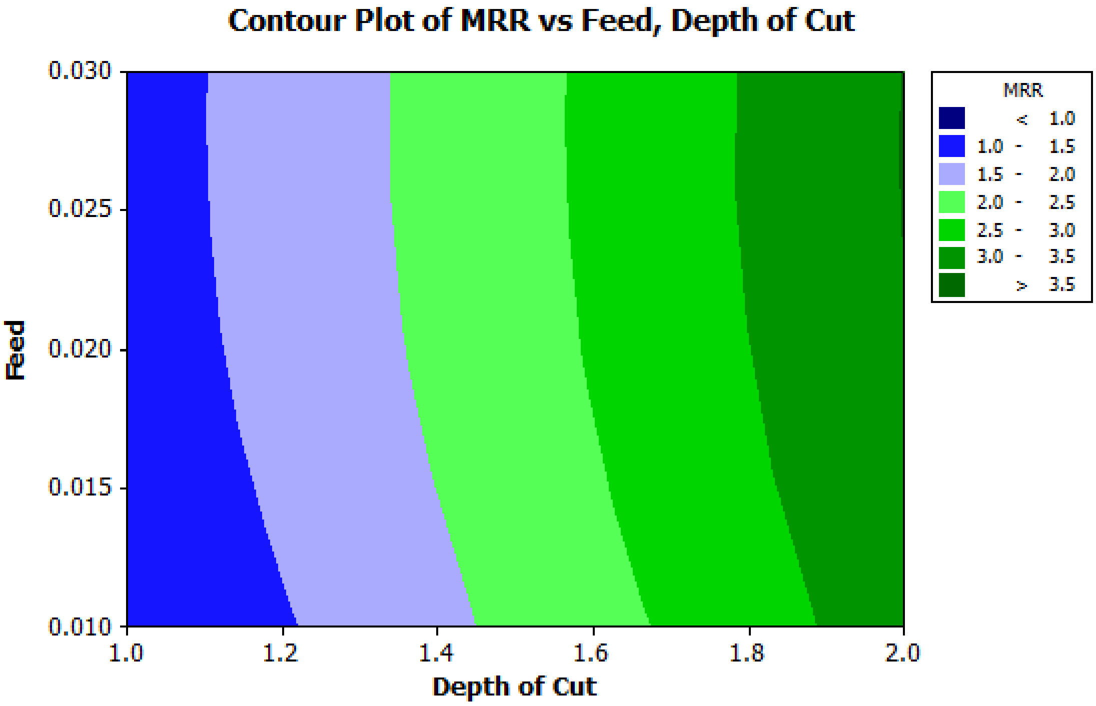



Contour Plot of Vibration Level vs Speed, Depth of Cut
Speed
200
180
160
140
120
100
1.0
1.2
1.4
1.6
1.8
2.0
Depth of Cut
Vibration Level
< 0.001
0.001 - 0.002
0.002 - 0.003
0.003 - 0.004
> 0.004


Contour Plot of Vibration Level vs Feed, Depth of Cut
Feed
0.030
0.025
0.020
0.015
0.010
1.0
1.2
1.4
1.6
1.8
2.0
Depth of Cut
Vibration Level
< 0.001
0.001 - 0.002
0.002 - 0.003
0.003 - 0.004
> 0.004


Contour Plot of MRR vs Speed, Feed
Speed
200
180
160
140
120
100
0.010
0.015
0.020
0.025
0.030
Feed
MRR
< 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
> 3.5


Contour Plot of MRR vs Speed, Depth of Cut
Speed
200
180
160
140
120
100
1.0
1.2
1.4
1.6
1.8
2.0
Depth of Cut
MRR
< 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
> 3.5



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