Multi-response Optimization for Hard Turing Process of AISI M2 (62-64 HRC): A Case of a Cutting Tool Manufacturing Industry

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ABSTRACT

In the present research paper, the multi-response optimization is done by employing the multi-response performance index (MRPI) considering the response characteristics such as surface roughness, resultant cutting force, and resultant vibration signals for AISI M2 tool steel. The main aim of this paper is to combine the effect of all response characteristics to obtain the one single response, so after setting machining parameters in CNC machine we will get the minimum cutting force, minimum vibration, and minimum surface roughness.The present investigation shows that the multi-response signal has increased with an increase in cutting speed, decreases with increase in feed rate, and initially decreases with increase in depth of cut up to 0.5 and then increase.

Keywords: MRPI, AISI M2, Surface Roughness, Resultant Cutting Force, Resultant Vibration Signal.

I. INTRODUCTION

The turning process is common machining process in every industry. The optimization of any machining process, including gives various benefits to the company such as minimization of machine setting time, minimization of machine idle time, minimization of tooling cost by improving tool life, therefore the machining process made more economical and efficient to maximize the profit of any company. The present investigation is related to cutting tool manufacturing company named as Birla Precision Technologies Ltd., Nashik. The present investigation’s main aim was to improve the efficiency and performance of CNC turning department by minimizing resultant cutting force and resultant vibration signal with the better surface finish. If it will be possible to replace the existing cylindrical grinding process by setting muti-response optimized parameter in CNC machine, then management is ready to replace it with some products.

In multi-response optimization, weight criteria of each objective are significant for producing better and accurate solutions. In this investigational analysis, the optimum machining parameters are estimated using Taguchi based multi-response performance index on turning of AISI M2 tool steel with PCBN insert tools. This method has been employed for simultaneous minimization of surface roughness, resultant cutting force, and resultant vibrational signal. The proper selection of machining factors is achieved by optimization techniques in turning operation [3]. An efficient methodology of Taguchi’s method used to select optimum parameters and

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this method eliminates the need for repetitive experiments by which material, time and cost saved [1]. Taguchi's method is best appropriate for single objective optimization problem only. In practice most of the industrial processes are multi-response optimization problem, therefore, Taguchi's method is altered into multi-response optimization technique by various researchers [4]. Taguchi based utility concept is a multi-objective optimization technique employed to optimize the multi-objective simultaneously in turning operation at various machining parameter combination [5]. In the utility concept, the weight factor is multiplied with each SN ratio of the output to obtain a multi SN ratio [6]. Taguchi based utility concept has been employed for optimizing the machining parameters in turning of free machining steel with carbide tool [5]. Taguchi based utility concept is a multi-objective optimization has been employed for optimization of machining parameters in turning operation of AISI202 austenitic stainless steel with CVD coated carbide tool [7]. Optimum machining parameters and minimum quantity of lubricant are found using Taguchi's method together with utility concept in turning operation of brass with K10 carbide tool [8]. The evaluation of optimum machining parameters for obtaining good surface quality using Taguchi concept coupled with PCA [9]. Electric Discharge Machining parameters were optimized using modified PCA based utility concept [10]. PCA has been employed to assign weight criteria to each objective [11]. The tool life and surface finish can be enhanced by properly controlling the cutting forces in machining process [12]. The surface finish is used to estimate fatigue strength, corrosion resistance and wear resistance of the machined component [1]. The high precision machined parts essential in the critical application and is accomplished by the high surface finish. In manufacturing, high surface roughness is unwanted and must be controlled to estimate the performance of the mechanical components. [13].The achievement of high production rate is achieved with the help of high metal removal rate in turning operation [14]. The high material removal rate is usually desirable and it acts major responsibility in turning operation [5].The multi-objective optimization was done to improve the material removal rate and to improve surface finish for HSS M2[17].

The main aim of this investigation is to estimate the optimal combination and significant of machining parameters for minimization of surface roughness, resultant cutting force and resultant vibration signal using the application of the Taguchi based multi-response performance index and ANOVA in CNC turning operation of AISI M2 tool steel using PCBN insert tool.

II. EXPERIMENTATION

The trails are conducted under the supervision of management representative and experimentation facility providing institute such as Vishwakarma Institute of Information Technology, Pune. The total experimental setup to collect the data related to average surface roughness value (Ra), resultant cutting force, and resultant vibration signal is as shown in Figure 1.

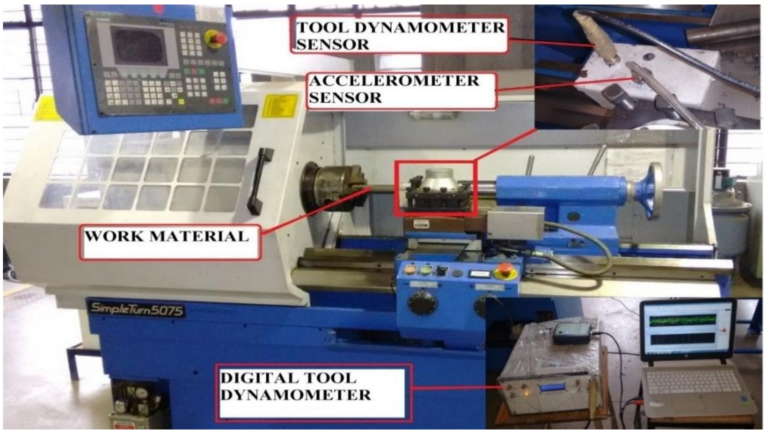

Figure 1 Experimental Setup at VIIT,Pune

The CNC machine used in this experimentation is ACE make and model simple turn 5075 with Siemens 802controller. The CNC lathe has a maximum spindle speed of 2000 rpm and a power of 380 v/4.5v.The CNC lathe has 250 mm maximum turning diameter and 700 mm maximum turning length. The all experimental trials are conducted without coolant and as per sequence of the design of orthogonal matrix. Figure 1 shows the actual photograph of experimental set-up to measure corresponding three component of the cutting force namely tangential force (Fz), feed force (Fx) and radial force (Fy) and vibration signals acquired in three directions. The experimental set-up mainly consists of the CNC machine (Simple Turn 5075), FFT analyzer, digital tool dynamometer and sensor, accelerometer sensor.

III. APPLICATION OF MULTI-RESPONSE OPTIMIZATION

In the present work, a multi-response methodology based on Taguchi's technique and multi-response performance index is used for optimizing the multi-responses i.e. surface roughness, resultant vibration signal, and resultant cutting force. Taguchi proposed many different possible S/N ratios to obtain the optimum parameters setting, one of them is chosen for current work which is smaller is better for all response factors.

$$\sum Vr * 1/Vr = Wvr \quad (1)$$

$$\sum CFr * 1/ CFr = Wcfr \quad (2)$$

$$\sum SRa * 1/ SRa= Wsra \quad (3)$$

We have used Equation (1), Equation (2), and Equation (3) to calculate weights for response factors (see Table 1). Multi Response Performance Index can be calculated using following Equation (4)

$$(MRPI)_1 = (Vr_1 *Wvr_1) + (CFr_1*Wcfr_1) + (Sra_1*Wsra_1) \quad (4)$$

Similarly, We can calculate $(MRPI)_2$,..............,$(MRPI)_{27}$

Table 1 Weight Calculations for Each Response Factors

Vr(Hz)	1/Vr	Wvr	CFr(N)	1/CFr	Wcfr	SRa(μm)	1/Sra	Wsra
2844.52	0.00035	31.04	284.4	0.0035	31.792	0.51	1.97	29.75
3443.94	0.00029	25.64	372.6	0.0027	24.262	0.71	1.41	21.23
2766.56	0.00036	31.92	441.3	0.0023	20.487	0.91	1.09	16.50
3425.41	0.00029	25.78	294.2	0.0034	30.732	0.91	1.09	16.50
3401.44	0.00029	25.96	578.7	0.0017	15.624	0.87	1.15	17.33
3449.09	0.00029	25.60	686.5	0.0015	13.170	1.13	0.88	13.30
3408.1	0.00029	25.91	696.3	0.0014	12.985	0.68	1.48	22.28
3405.21	0.00029	25.93	833.5	0.0012	10.846	0.89	1.12	16.87
3339.84	0.00030	26.44	304.0	0.0033	29.740	0.49	2.05	30.97
3435.84	0.00029	25.70	196.1	0.0051	46.101	0.42	2.40	36.18
3366.57	0.00030	26.23	284.4	0.0035	31.791	0.38	2.65	40.02
3364.8	0.00030	26.24	333.4	0.0030	27.116	0.50	1.99	29.95
3429.06	0.00029	25.75	215.7	0.0046	41.910	0.33	3.06	46.14
3427.28	0.00029	25.76	274.6	0.0036	32.927	0.36	2.78	41.87
3423.36	0.00029	25.79	323.6	0.0031	27.938	0.56	1.78	26.76
2866.92	0.00035	30.80	186.3	0.0054	48.525	0.27	3.66	55.15
3426.14	0.00029	25.77	274.6	0.0036	32.927	0.40	2.52	38.00
3433.62	0.00029	25.71	490.3	0.0020	18.439	0.49	2.04	30.76
2647.98	0.00038	33.34	176.5	0.0057	51.223	0.88	1.13	17.06
3262.74	0.00031	27.06	205.9	0.0049	43.906	0.35	2.86	43.07
2810.94	0.00036	31.41	245.1	0.0041	36.880	0.47	2.11	31.85
3439.86	0.00029	25.67	176.5	0.0057	51.223	0.27	3.66	55.15
2827.03	0.00035	31.23	235.3	0.0042	38.416	0.34	2.91	43.90
3421.24	0.00029	25.81	245.1	0.0041	36.880	0.56	1.80	27.08
3450.82	0.00029	25.59	186.3	0.0054	48.528	0.37	2.73	41.11
3389.91	0.00029	26.05	245.2	0.0041	36.879	0.41	2.46	37.07
3386.19	0.00030	26.07	254.3	0.0039	35.554	0.61	1.64	24.71
∑Vr = 88294.41			∑CFr = 9040.6			∑ SRa = 15.07		

Table 2 Multi-Response Performance Index and S/N ratio for Each Trail

CUTTING SPEED	FEED RATE	DEPTH OF CUT	MRPI	S/N RATIO
100	0.10	0.4	3528.87	-70.9527
100	0.10	0.5	2998.17	-69.5371
100	0.10	0.6	3267.65	-70.2847
100	0.15	0.4	3326.56	-70.4399
100	0.15	0.5	2675.74	-68.5489
100	0.15	0.6	2572.91	-68.2085
100	0.20	0.4	2493.05	-67.9346

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100	0.20	0.5	2448.81	-67.7791
100	0.20	0.6	3146.20	-69.9557
140	0.10	0.4	3656.01	-71.2601
140	0.10	0.5	3071.01	-69.7456
140	0.10	0.6	3040.69	-69.6595
140	0.15	0.4	3328.38	-70.4447
140	0.15	0.5	3055.77	-69.7024
140	0.15	0.6	3092.32	-69.8057
140	0.20	0.4	3711.61	-71.3912
140	0.20	0.5	3122.66	-69.8905
140	0.20	0.6	2619.99	-68.3660
180	0.10	0.4	4565.98	-73.1907
180	0.10	0.5	3540.65	-70.9817
180	0.10	0.6	3722.19	-71.4160
180	0.15	0.4	3495.92	-70.8712
180	0.15	0.5	3570.40	-71.0543
180	0.15	0.6	3448.85	-70.7535
180	0.20	0.4	3655.60	-71.2592
180	0.20	0.5	3311.67	-70.4009
180	0.20	0.6	3445.04	-70.7439

Table 2 shows the Multi-Response Performance Index calculated for each trail and respective S/N ratio.

IV. ANOVA FOR MULTI-RESPONSE OPTIMIZATION

Table 3 and Table 4 shows that in multi-response optimization cutting speed is the most significant factor which affects the all response factors and the second one is a depth of cut.

Table 3 ANOVA for Multi-Response Optimization

SOURCE	DOF	SEQ.SS.	ADJ.SS	ADJ.MS.	F-VALUE	P-VALUE
Cutting Speed	2	16.377	16.377	8.1886	14.26	0.000
Feed Rate	2	5.592	5.292	2.6461	4.61	0.023
Depth of Cut	2	6.578	6.578	3.2892	5.73	0.011
Residual Error	20	11.485	11.485	0.5743		
Total	26	39.733				

Table 4 Response Table for S/N Ratios of Multi-Response Optimization

LEVEL	CUTTING SPEED	FEED RATE	DEPTH OF CUT
1	-69.29	-70.78	-70.86
2	-70.03	-69.98	-69.74
3	-71.19	-69.75	-69.91
Delta	1.89	1.03	1.12
Rank	1	3	2

V. RESULTS AND DISCUSSION

Figure 2 shows that the optimize level i.e. A1 (cutting speed = 100 mm/min), B3 (Feed Rate = 0.20 mm/rev), and C2 (Depth of Cut = 0.5 mm) at which, we get the minimum resultant vibration signal (i.e.3249 Hz), minimum resultant cutting force (i.e. 281.50 N), and minimum surface roughness (i.e. 0.4683 µm).

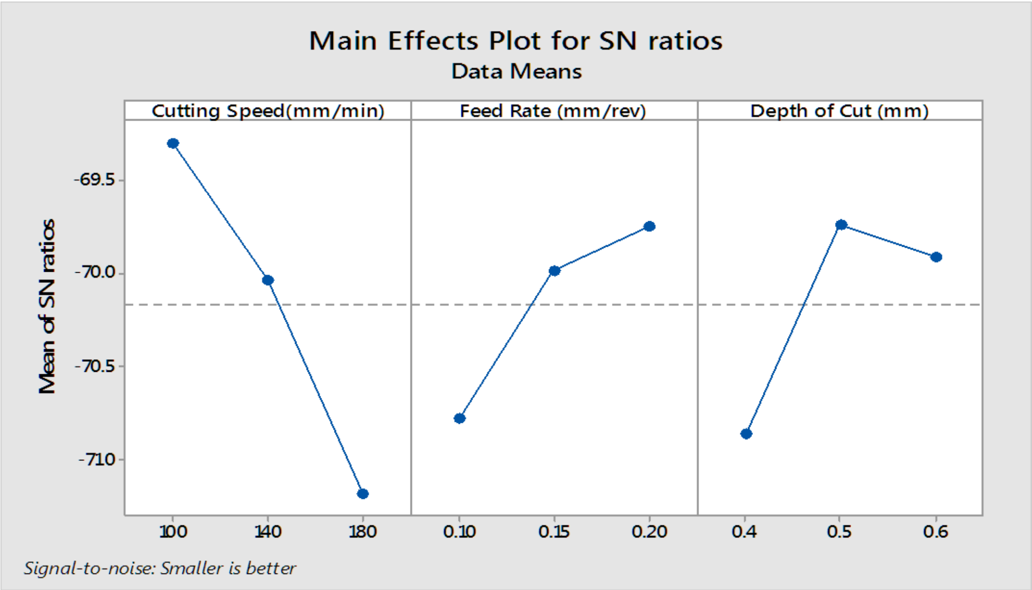

Figure 2 Main Effects Plot for Single to Noise Ratios of Muti-Response

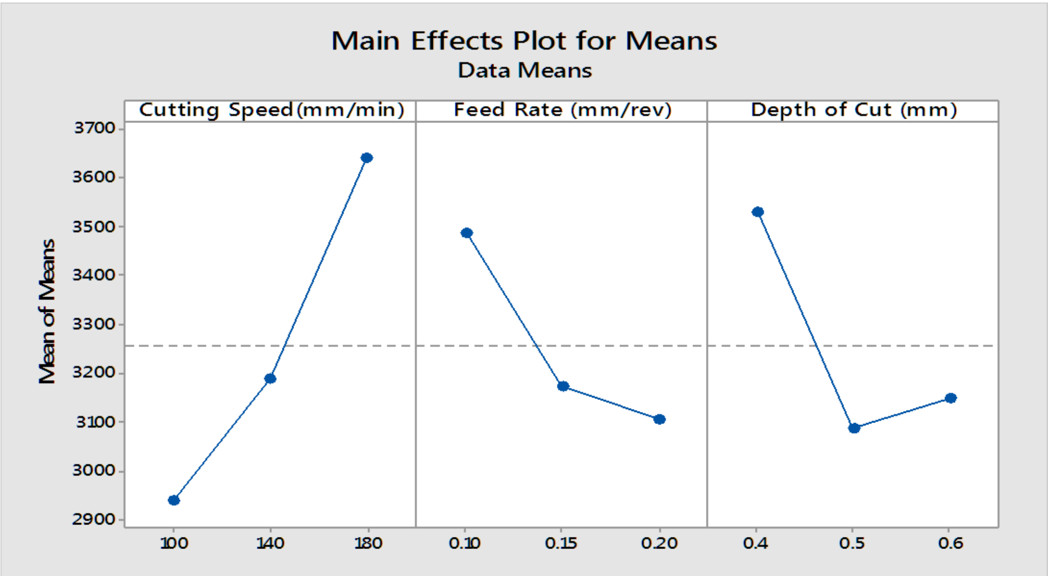

Figure 3 Main Effects Plot for Means of Muti-Response

Figure 3 shows the main effects plot for means of muti-response. It shows the multi-response signal is increased with increase in cutting speed, decreases with increase in feed rate, and initially decreases with increase in depth of cut up to 0.5 and then increase.

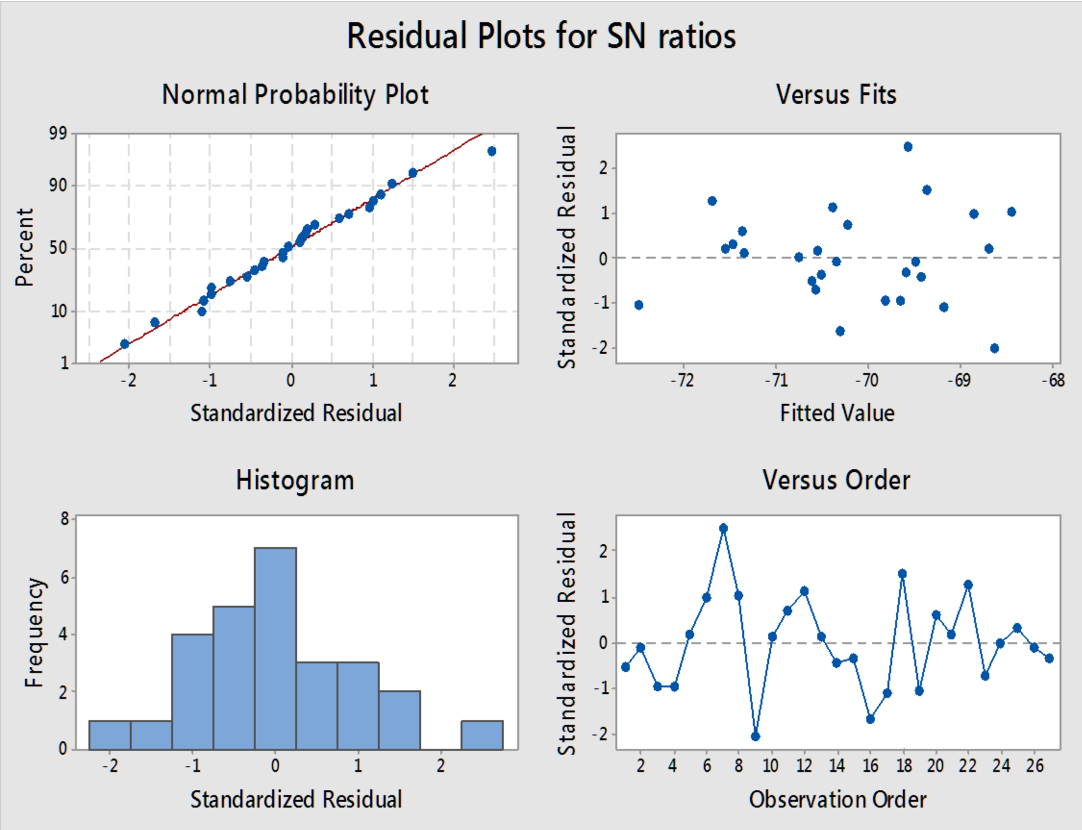

Figure 4 Residual Plots for Single to Noise Ratios of Muti-Response

Figure 4 shows the normal probability plot and histogram with the distribution of multi-response signals data. The normal probability plot shows that the recorded signals follow the straight line so the model designed for present investigation is accurate.

VI. CONCLUSIONS

The present research work is done multi-response optimization for CNC turning process of AISI M2 tool steel. The conclusions of present research work is as follows:

- The multi-response optimization shows that the optimize level is A1 (cutting speed = 100 mm/min), B3 (Feed Rate = 0.20 mm/rev), and C2 (Depth of Cut = 0.5 mm) at which, we get the minimum resultant vibration signal (i.e.3249 Hz), minimum resultant cutting force (i.e. 281.50 N), and minimum surface roughness (i.e. 0.4683 µm).
- The multi-response signal is increased with increase in cutting speed, decreases with increase in feed rate, and initially decreases with increase in depth of cut up to 0.5 and then increase.

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