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Taguchi Design Optimization of Machining Parameters in CNC End Milling of NIMONIC 75

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Abstract— *This paper introduces the Taguchi optimization method to optimize the machining parameters of Nimonic 75 by CNC end milling. Taguchi analysis aids to know, the influence of machining parameters on results like surface roughness. CNC milling is the flexible process for material removing. Desired complex shapes can be produced by using CNC mill. It is fully automated, gives highly precision dimensions and surface finish. Nimonic 75 is a special grade heat resistant nickel based super alloy. It has wide range of applications in aerospace, chemical, marine, furnaces, heat exchangers equipments etc due to its extreme capability to withstand at extreme temperature, pressure and corrosion. In the present work, the end milling of Nimonic 75 is carried to analysis by means of Taguchi method with the help of software MINITAB 14.0. The experimentation is done by means of Taguchi orthogonal array $L_{27}(3^3)$, 27 trials . Here input parameters are spindle speed (s), feed (f) and depth of cut (d), output response is average surface roughness R_a (µm).*

Keywords—Taguchi Method, Surface Roughness, Optimization, Nimonic 75, CNC End Milling, Orthogonal Array.

I. INTRODUCTION

Automation plays a prominent role in today's industrial manufacturing systems. Automation is simply a process of performing an operation without human assistance. The CNC machines are the main components in the automation. There are a wide range of CNC machines available today which will perform different operations. Enormous changes occurred in the manufacturing systems due to CNC machines. Some of them are turning machines, milling machines, wire EDM, plasma arc machines, laser beam machines etc. The main intension of these machines is to remove the unwanted material from the work piece to get the desired geometrical shape with accurate dimensions and finish. The working of a CNC machine is defined by the coded data of alphabets and numerical in the form of a software program.

The machining selected in the present work is CNC end milling. CNC end milling is one of the most important and widely used material removal methods in the fields like aerospace, automotives and precision manufacturing works where quality is the essential parameter [1, 2]. Today's modern manufacturing world requires more precise products and goods. The two important criteria of any machining are the Quality and productivity. The quality of a machined part is mainly based on the surface roughness obtained from machining. Surface finish is a quality index mainly influences machining time and productivity [3]. The surface roughness is mainly influenced by the machining parameters and errors occurred in machine during machining like vibrations, tool wear etc [4]. Surface roughness plays a vital role in cost, appearance, strength, surface friction, thermal and electrical contact resistance, fatigue, ability of holding lubrication and corrosion resistance [5]. Different types of surface roughness amplitude parameters are available they are maximum peak-to -valley roughness (R_{max} or $R_{y)}$, root mean square (RMS) roughness(R_q), arithmetic mean surface roughness value (R_a) [4]. Since R_a is the extensively used roughness index, so it is selected as response factor [5].

1.1. Work piece details

The work piece material selected is a nickel based alloy Nimonic 75. Nimonic 75 is a heat resistant super alloy [6]. Its main properties are corrosive resistance, high pressure and temperature resistance. Nimonic 75 chemical composition is 5.0% max Iron, 0.5% max Copper (Cu), 1.0% max Silicon (Si), 1.0% max Manganese (Mn), 0.2-0.6% titanium (Ti), 18.0-21.0% Chromium (Cr), 0.08-0.15% Carbon (C) and the remaining is Nickel (Ni). The maximum chemical composition of Nimonic 75 is Nickel (Ni) and then Chromium (Cr) [7]. Due to its special properties Nimonic 75 has wide range of applications in various engineering fields. Some of them are aero space, nuclear, marine, chemical etc. Nimonic 75 is used in manufacturing the components such as fasteners, turbine blades, valves, after burners, compressors, hush kits, ducting systems, thrust reversals, exhaust systems etc [8]. The various Nimonic alloys are Nimonic-80A, Nimonic-

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105, Nimonic-90, Nimonic C-263, Nimonic-86, Nimonic c80A, Nimonic 115 etc [8].

1.2. Cutting Tool and Machine Details:

The cutting tool used for the work is a solid end mill carbide cutter shown in "Fig. 1". The mill cutter has four flutes on its single side and the other end is plain and fixed in the tool holder. The diameter of the mill cutter and the shank diameter are 10mm. The length of cut is 14mm and the overall length of the mill cutter is 51mm.300 right hand spiral, right hand cut. These mill cutters are mainly used in finishing operations and profiling. The machine selected for the work is HAAS-VF2 vertical CNC mill and its specifications are given in "Table 1".

Fig.1: End Mill Cutter

Table 1: CNC Mill (HAAS-VF2) Specifications

S.No	ELEMENT	SPECIFICATION
1	Coolant Capacity	208L
2	Machine Weight	3311Kg
3	Max Tool Diameter	89mm
4	Max Tool Weight	5.4Kg
5	Table length × Width	914 ×356mm
6	Max Speed	8100rpm
7	Max Torque	122Nm@2000rpm
8	Max Thrust X,Y,Z	11343N,11343N,18683N
9	Max Weight on Table	1361Kg
10	Power	195-260 VAC/50 A 354-488 VAC/30 A
11	Air Required	133L/min, 6.9 bar
12	Tool Changer Type, Capacity	Carousal 20

1.3. Technical data of SURFTEST SJ-210:

For measuring the surface roughness of the machined work surface, Mututoyo SURFTEST SJ-210 is used. It is a portable surface roughness measuring instrument. Its technical details are given in "Table 2".

Table 2: *Specifications of Surftest*

S.No	Element	Specification
1	Measuring range	X Axis 17.5mm, transverse tracing drive unit
2	Applicable Standards	ANSI, VDI, JIS-82, JIS-94, JIS-01
3	Detector range	360µm
4	Measuring method	Skidded
5	Measuring force	0.75Mn
6	Analysis graphs	Bearing area/Amplitude distribution curve
7	Measuring force	0.75mN

II. TAGUCHI METHOD

Genichi Taguchi was developed a philosophy and methodology for improving the quality of Japanese Industrial Products at low cost in 1940, which depends majorly on Statistical tools, concepts, and designed experiments [9]. This Taguchi technique was followed by several fields of industries, Engineers to approach good profit values by improving product's quality at optimal cost. The key of impact for this method is merging the statistical and engineering methods to reach hasty progress in quality and cost thru optimizing product design and production steps [10]. Actually this process involves that the proper selection of factors as per responses of processes, number of tests and these selected factors are arranged in the form of Lattice Square model with help of Design of Experiments process, and then this square model is called as Orthogonal Array. The test results are optimizing through the analyzers like Signal to Noise Ratio (S/N Ratio), Response Surface Method (RSM) techniques etc. choosing the correct control factors is the vital phase in the Taguchi design analysis [11].

2.1. Signals to noise (s/n) Ratio

In Taguchi method, Signal to Noise Ratio (S/N Ratio) is the Statistical measuring process for determining the optimum factors to respected Responses. The experimental investigation details are converted into signal to noise ratios (S/N). The smaller the better, the higher the better and the nominal the better are three sorts for the signal to ratio for examine the Factor's enactment

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[12]. In this study, smaller the better signals to noise ratio characteristic is selected for obtaining optimum response i.e. surface roughness, as given in Eq. (1). From the definition of Taguchi, the product quality is presented as loss occurred to the society during shipping by the product or goods. The products do not reach their targeted goals because of their uncontrollable noise factors, which will affect their functional characters. The various noise factors are like human errors, machine vibrations, tool wear, excess temperatures etc.

$$(S/N) = -10\log_{10} [1/n \sum_{i=1}^{n} (Y_i^2)] \quad (1)$$

Where, n = no. of tests or experiments or trials,
Y_i = Response Factor value for i^{th} trial.

III. EXPERIMENTAL DESIGN AND EXPERIMENTATION

The numbers of control factors are three and responses are one. By considering the control factors and their levels a standardized Taguchi design experimental $L_{27}(3^3)$ orthogonal array (i.e. 27 experimental trials) was selected for experimentation as given in "Table.3". The machining parameters, corresponding codes and their levels are given in "Table.4". In this study, the independent variable are the machining parameters speed, feed and depth of cut) while the dependent variables are the output response (surface roughness). The Nimonic 75 work pieces are prepared for machining by removing surface irregularities by filing. The experimentation is conducted by fixing the Nimonic 75 work pieces in the vice of CNC HAAS-2F vertical mill work table as shown in "Fig. 2". The machining parameters are taken from the Taguchi design of experiments method by using the software MINITAB 14.0. After completion of 27 trials of experiment by using Taguchi $L_{27}(3^3)$ orthogonal array, the work pieces are removed from the CNC machine vice and further examined to measure the surface roughness of each cutting slots. The machined work pieces are shown in "Fig. 3". Mututoyo SURFTEST-SJ210 surface roughness measuring instrument is used for measuring surface roughness as shown in "Fig. 4". The average surface roughness value (R_a) is calculated at three different points on the machined slots (R_1, R_2, and R_3). The average of three roughness values is taken as final surface roughness value (R_a), as given in Eq. (2).

$$R_a = (R_1+R_2+R_3)/3 \quad (2)$$

Where, R_1, R_2 and R_3 are the measured surface roughness values at three different points on the machined slots. The measured average surface roughness (R_a) values are given in "Table 5".

Since Nimonic 75 belongs to hard metals category, therefore more heat is generated during machining operation. This heat tends to poor surface finish, excess tool wear. The solution for this problem is lubrication. The main functions of a lubricant is to reduce friction, increases tool life, reduces heat produced during operation, removes chips and makes cutting zone clean. During machining operation lubrication is used for getting good surface finish and also to decrease friction and heat produced.

***Table 3:** The basic Taguchi $L_{27}(3^3)$ orthogonal array with control factors and levels*

S.No	A	B	C
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

***Table 4:** Machining parameters, codes and their levels used for orthogonal array*

Parameters	Code	Level 1	Level 2	Level 3
Spindle speed(rpm)	A	1000	1100	1200
Feed(mm/min)	B	300	350	400
Doc(mm)	C	0.100	0.125	0.150

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Fig.2: *Milling Operation with Coolant*

Fig.3: *End Mill Slots with 10mm width on Nimonic 75*

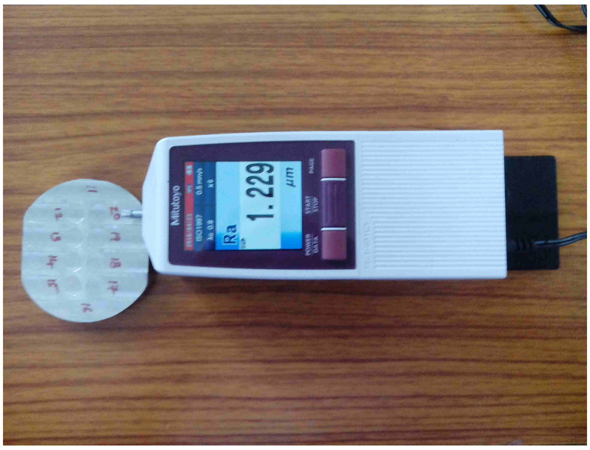

Fig.4: *Surface Roughness Measuring*

IV. RESULTS AND DISCUSSION

The measured values of surface roughness are uploaded to MINITAB 14 software and obtained signal to noise ratio (S/N) values as given in "Table 5". In order to determine the minimum surface roughness value (R_a) would be the ideal situation for this study, smaller the better signal to noise ratio characteristic was used. The optimal set of input factors of the experiment is determined from the graph in "Fig 5" and "Table 6". S/N ratio for each level of control parameters surface roughness (Smaller is better). The optimum surface roughness value R_a (1.0030µm) is obtained at spindle speed (A) 1100rpm (level-2), at feed (B) 300mm/min (level-1) and at depth of cut (C) 0.100mm (level-1). Thus, the minimum surface roughness value (best surface finish) was found to be A2-B1-C1, which is the optimized set of levels for all the three input machining factors. Maximum surface roughness value R_a (3.0150µm) is obtained at spindle speed 1200rpm, feed 400mm/min and depth of cut 0.150mm.

Table 5: *Response (surface roughness) variable with corresponding signals to noise (S/N) ratios*

Run order	Inner control factor array			R_a(µm)	S/N
	A	B	C		
1	1	1	1	1.2400	-1.86843
2	1	1	2	1.2540	-1.96595
3	1	1	3	1.7151	-4.68579
4	1	2	1	1.1850	-1.47437
5	1	2	2	1.9830	-5.94645
6	1	2	3	2.0130	-6.07688
7	1	3	1	1.9320	-5.72014
8	1	3	2	2.0470	-6.22236
9	1	3	3	2.1120	-6.49388
10	2	1	1	1.1004	-0.83101
11	2	1	2	1.1270	-1.03848
12	2	1	3	1.3830	-2.81644
13	2	2	1	1.2320	-1.81221
14	2	2	2	1.2580	-1.99361
15	2	2	3	1.8830	-5.49701
16	2	3	1	1.2650	-2.04181
17	2	3	2	1.8280	-5.23952
18	2	3	3	1.4560	-3.26323
19	3	1	1	1.1100	-0.90646
20	3	1	2	1.2290	-1.79104
21	3	1	3	2.8340	-9.04800
22	3	2	1	1.1330	-1.08460
23	3	2	2	1.1890	-1.50364
24	3	2	3	2.7040	-8.64013
25	3	3	1	2.8800	-9.18785
26	3	3	2	2.9640	-9.43756
27	3	3	3	3.0150	-9.58575

Table 6: *Response table for signal to noise ratio Surface Roughness (Smaller is better)*

Level	Speed	Feed	DOC
1	-4.495	-2.772	-2.770
2	-2.726	-3.781	-3.904
3	-5.687	-6.355	-6.234
Delta(Δ)	2.961	3.582	3.464
Rank	3	1	2

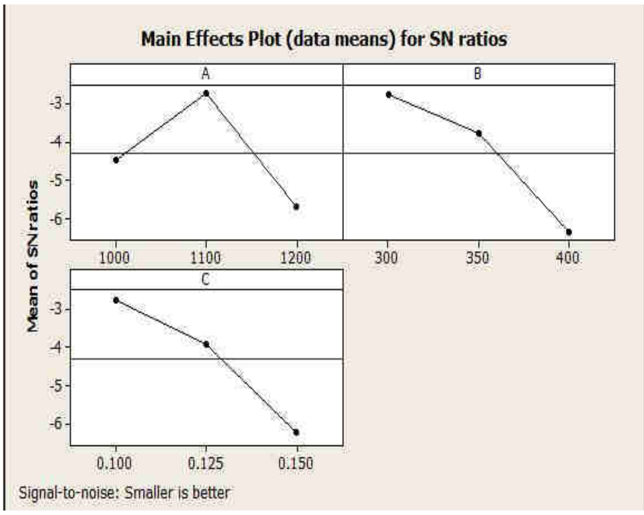

Fig. 5: *S/N ratio and means effects for each control factors.*

V. CONCLUSION

Surface roughness analysis by Taguchi method for CNC end milling of Nimonic 75 is done. The most important input machining parameter that affects the surface roughness is the feed then depth of cut and finally the spindle speed. Feed is the maximum contributing factor of surface roughness. Since feed and depth of cut are the predominant factors in the machining of Nimonic 75. Increasing the feed and depth of cut would increases the tool wear rate thus more friction and heat was generated. In order to minimize the tool wear, heat and friction generated during machining Nimonic 75, a liquid coolant (oil based) is used.

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