ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

IARJSET

International Advanced Research Journal in Science, Engineering and Technology

2nd International Conference on Advances in Mechanical Engineering(ICAME-2016)

Amrutvahini College of Engineering, Sangamner

Vol. 3, Special Issue 1, March 2016

On the Influence of Cutting Parameters on Machined Surface Flatness in Precision Turning of Nickel Alloy

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Abstract: Recent days Nickel material has increasing applications in the manufacturing of various components and structure due to their inherent properties like as hardness. Nickel alloys are extensively used in aerospace, marine, and nuclear power generation, chemical, petrochemical and process industries. Nickel is an adaptable element and will alloy with most metals. At present very a small number of researchers developed precision machining processes with their useful parameters for the production of highly precise Nickel products. Enhanced surface integrity parameters can be achieved by the CNC turning process than with conventional grinding techniques. Present paper focuses the need of finding out machining characteristics of Nickel using high quality machine tools like CNC precision turning and the experiments were conducted according to Taguchi DOE with L 9 OA. The output parameter as machined surface flatness is analysed by using ANOVA. Spindle speed is having dominating effect on final machined surface flatness and minimum surface flatness is achieved up to 2.6 µm.

Keywords: Nickel, Precision Turning, Flatness, Taguchi DOE, ANOVA.

I. INTRODUCTION

Nickel alloys are widely used in the manufacture of various components and structures for aerospace, marine, and nuclear power generation, chemical, petrochemical and process industries. In the aerospace industry these alloys are used in the rotating parts of gas turbines such as blades and disks, housing components such as turbine casing, engine mounts and in components for rocket motors and pumps. They are also used as structural material for various components in the main engine of space shuttles, in cryogenic tank age and for pressure vessels of Nickel-hydrogen batteries used in the space station [1].

All these applications of Nickel alloys are made possible on account of properties such as high yield strength and ultimate tensile strength, high fatigue strength, corrosion and oxidation resistance even at elevated temperatures, non-magnetic characteristics and low creep [2]. Nickel alloys are widely employed in the aerospace industry, in particular in the hot sections of gas turbine engines, due to their high temperature strength and high corrosion resistance. They are known to be among the most difficult-to-cut materials. In turning Nickel alloy, it is well known that the tool temperature rises easily due to its poor thermal properties. In addition, precipitate hardening of secondary phase (Ni_3Nb) together with work hardening during machining makes the cutting condition even worse. All these difficulties lead to high tool wear less material remove rate (MRR) and poor surface finish [3,5].

Considerable research has been done on selection and optimization of machining parameters for coated and uncoated carbide cutting tools using wet and dry cutting conditions. However understanding the wear mechanism of turning and turning operations, are very important in the aerospace industry for desired surface flatness and economic manufacturing of the product. Surface finish is a very important aspect for designing mechanical elements and also presented as a quality indicator of manufacturing processes [6].

The present investigation aims at quantitative as well as qualitative analysis of surface topography of the machined surface produced using CNC turning operation on pure Nickel alloy by carbide inserts. The analyzed results could help prescribe suitable machining techniques that produce most favourable and acceptable surfaces for precision applications.

II. EXPERIMENTAL WORK

A. Process, Equipment and Tooling

Precision CNC turning process was employed for investigation on surface flatness of Nickel alloy. Table I shows the specifications of CNC turning machine used for carrying out the experiments.

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TABLE I: SPECIFICATION OF PRECISION CNC TURNING MACHINE

Sr.No.	Machine Parts	Details	Dimensions/Sizes
1	Capacity	Swing over bed	ø300 mm
		Std. Turning Diameter	ø165 mm
		Max. Turning Diameter	ø250 mm
		Dist. Between Centre	350 mm
		Max. turning length	300 mm
2	Slides	Cross (X axis) Travel	140 mm
		Longitudinal (Z axis) Travel	300 mm
		Rapid Feed (X & Z axis)	24 m/min
3	Main Spindle	Spindle Motor	5.5/7.5 KW (15 min. rating)
		Spindle Bore	ø38 mm
		Spindle Nose	$A_2$5
		Max. Bar Capacity	ø25 mm
		Chuck Size	ø165 mm
		Speed Range	50-4000 rpm
		Full Power Speed Range	1000-3000 rpm
4	Turret	No. of Stations	8
		Tool Size	20 x 20 mm
		Max. Boring Bar Capacity	Ø 50
5	Other Data	Weight (Approx)	2500 Kg.
		Machine Dimensions (L x B x H)	2200 x 1400 x 1550
6	Accuracy	Positioning Accuracy	0.015
		Repeatability	± 0.003
7	Tail Stock	Quill Diameter	ø70 mm
		Quill Stroke	80 mm
8	Control System	Fanuc Oil Mate TC/Siemens 802D	

B. Experimental Design and Procedure

TABLE III: STANDARD DESIGN OF L9 ORTHOGONAL ARRAY

Expt. Run	**Column**			
	Factor A	**Factor B**	**Factor C**	**Factor D**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

A Taguchi experimental design L9 orthogonal array was used for designing the parameter combinations for each experimental trial (See Table II). In this orthogonal array, number of factors are 4 and number of levels are 3. Hence total numbers of runs are 9. The response variable chosen is the arithmetic average of surface flatness for the experiments in CNC turning of Nickel alloy. The input control factors selected for CNC turning of Nickel are: depth of cut (70-110-150 µm), feed rate (0.15-0.20-0.25 mm/rev), spindle speed (1500-2500-3500 rpm) and rake angle (0-5-7 degrees). Table III shows the experimental runs with the assigned factors to each of the columns of OA for CNC turning process respectively.

TABLE IIIII: EXPERIMENTAL LAYOUT USING L9 ORTHOGONAL ARRAY FOR NICKEL ALLOY

Expt. runs	**Depth of Cut (µm)**	**Spindle Speed (rpm)**	**Feed rate (mm/rev)**	**Rake Angle (Degrees)**
1	70	1500	0.15	0
2	70	2500	0.20	5
3	70	3500	0.25	7
4	110	1500	0.20	7
5	110	2500	0.25	0
6	110	3500	0.15	5
7	150	1500	0.25	5
8	150	2500	0.15	7
9	150	3500	0.20	0

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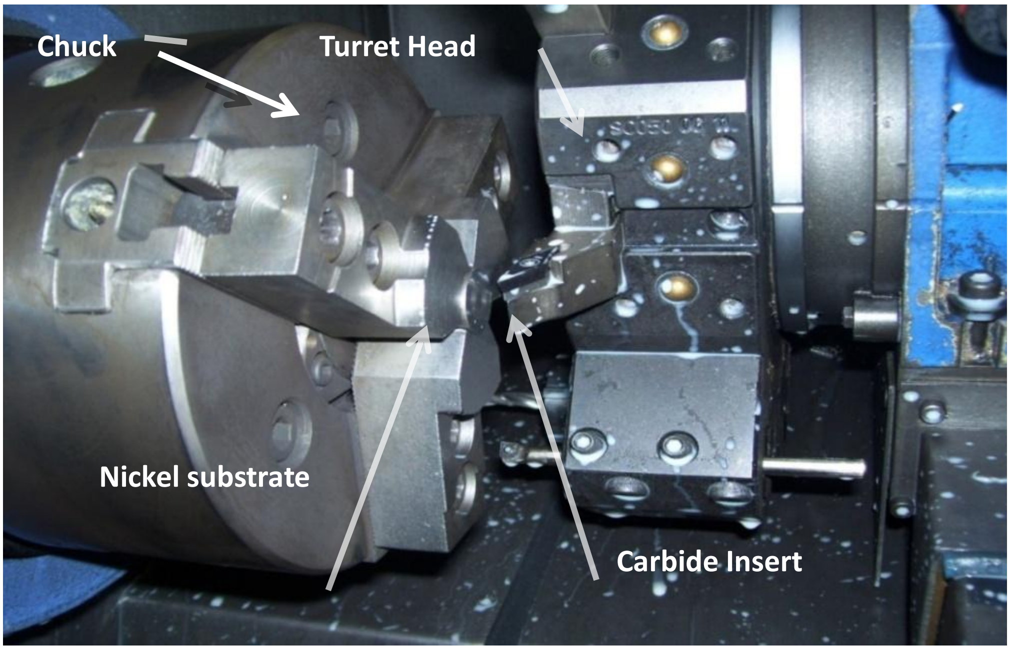

A closed up photograph of Precision CNC turning of Nickel substrate

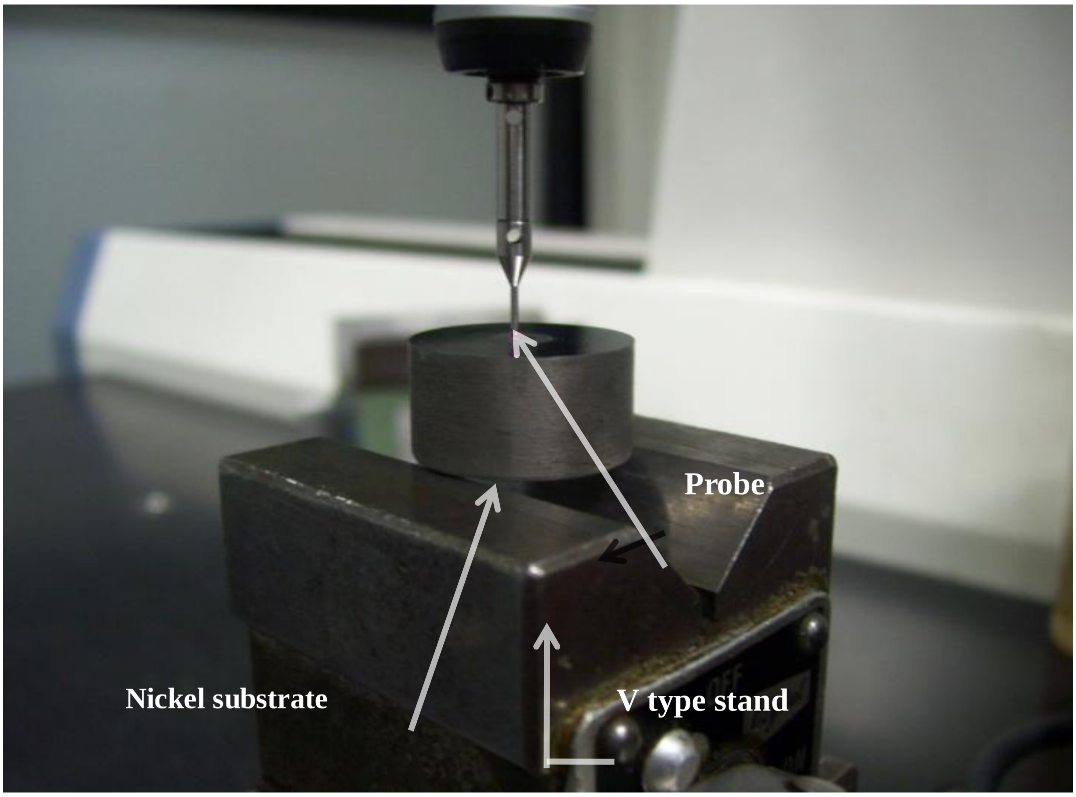

Fig. 1. Measurement on CMM

The preparation of experiments began with the cutting of nine work pieces to the required length from a long rod of Nickel. These substrates of Nickel are exactly made to size Ø25 x 10 mm thickness. The single substrate of Nickel is hold in three jaw chuck of CNC machine (see Fig. 1).

Initially, rough cut of 60 µm was taken on each substrate and finish cut was taken on surface of 24 mm diameter. Finally each substrate was machined as per data, which is fixed in L9 array. For protection of CNC faced surface from dust and swarf each substrate was stacked by a plastic sticky paper called as food wrapped paper.

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III. RESULTS AND ANALYSIS

The experiment was performed according to Taguchi L9 orthogonal array. Based on the experimental work, the results were analyzed and are presented in this section. The analysis was done to determine the significant factors influencing output variables using statistical software known as 'Minitab R-16'. An analysis was done to predict the response variable for the unknown value of the input factors. In this investigation the response variable was selected as surface flatness of the machined surfaces.

TABLE IVV: RESULTS OF FLATNESS IN CNC TURNING OF NICKEL ALLOY

Substrate No.	1	2	3	4	5	6	7	8	9
Flatness Value (µm)	3.2	4.8	7.2	2.6	9.4	4.7	3.6	10.4	12.6

All CNC machined surfaces were measured by contact type of measurement in a controlled environment temperature. The instrument is used for measuring the surface flatness of machined surfaces is CMM (see Fig. 2) Model Spectra 564 made by Accurate Co. having LC of 0.001µm. Table 4 shows the flatness values of machined surfaces.

A. Statistical Analysis of Surface Flatness

The main effect plot for flatness (ANOM) and the table of analysis of variance (ANOVA) are shown in Fig. 3 and Table 5. It is observed from the ANOVA table, there is no statistically significant factor in this experiment. Since he P-value in the ANOVA table for any input parameter is not less than 0.05, there is a not statistically significant relationship between any input parameter and the response variables at the 95.0% confidence level. Notice that the highest P-value is 0.240 in the ANOVA table. Since the P-value is not less than 0.05, that term is not statistically significant at the 95.0% confidence level. The percentage contribution of input variables influencing the flatness is depth of cut: 25.12 %, spindle speed: 50.05 % feed rate: @1 %, rake angle: 24.13 %. The effect of each input variables on the surface flatness in detail using ANOM plots.

TABLE V: ANOVA FOR PRECISION TURNING OF NICKEL ALLOY

Source	**DF**	**SS**	**MS**	**F**	**P**	**% Contribution**
Depth of cut	2	25.6	12.8	1.00	0.420	25.12
Spindle Speed	2	51.01	25.50	3.00	0.125	50.05
Feed rate	2	0.7	0.4	0.02	0.979	@1
Rake Angle	2	24.6	12.3	0.96	0.436	24.13
Error	0	0	-	-	-	-
Total	8	101.91	-	-	-	100

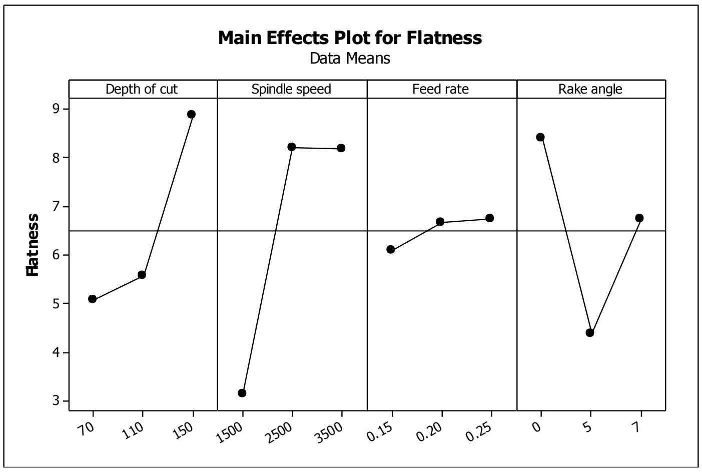

Fig. 2. Main effect plot for surface flatness in precision CNC turning of Nickel

- Effect of depth of cut

The main effects plot shows that there is a linear increasing trend of depth of cut on machined surface flatness. When the depth of cut is 70 µm the flatness is up to 5 µm. Further increment in depth of cut from 70 µm to 110 µm, there is increase in flatness rapidly in some magnitude up to 7 µm. Again the flatness is drastically increased up to 9 µm, when depth of cut is 190 µm. Hence, it is concluded that when increase in depth of cut there is increase in flatness value. When the depth of cut is minimum, continuous chips are produced due to smooth shearing action. Therefore, these chips generated by shear stresses, the former by separation along the simple shear plane, and later in shear zone. Therefore, the machined surface is smooth and accurate at minimum depth of cuts.

- Effect of spindle speed

In CNC precision turning operation spindle speed shows non linear effect on the flatness. From the main effect plot it is shown that the surface flatness is minimum i.e. 3 µm at 1500 rpm. However, at 2500 rpm the surface flatness is maximum it is about 8 µm. At 3500 rpm surface flatness is decreased in very small amount up to 7.8 µm. It is observed that when the spindle is high a sudden temperature rise in between tool and chip interface on account of higher friction. In this case burned black chips are generated while machining. At lower spindle speed the good quality of surface is generated during hard turning of Nickel alloy.

- Effect of feed rate

The main effect plot shows that there is a linear trend of feed rate on machined surface flatness of Nickel alloy. It is seen that when feed rate increase from 0.15 mm/rev to 0.20 mm/rev then there is drastic increase in flatness value from 5.8 µm to 6.8 µm. When there is a sudden increase in feed rate up to 0.25 mm/rev it results again increase in flatness value up to 7.2 µm. Hence, at minimum value of feed flatness is better. At the lower feed rates there is reduction in cross sectional area of deformation zone i.e. minimum surface flatness. At the highest level of feed rate the material removal area is more which cause in homogeneity in surface generation mechanism due to involvement of other factors during machining. Therefore, the flatness is maximum at this condition.

- Effect of rake angle

Rake Angle is having non linear trend in MEP's. The main effect plot shows that when rake angle is taken as 0° then value of flatness is maximum up to 8.5 µm. Hence, increase in rake angle of 5°, there is sudden decrease in flatness up to 4 µm. At 7° rake angle flatness is about 7.2 µm. At higher rake angles the distance between tool tip and workpiece surface is quiet less, therefore a smooth shearing action might be happened while in machining. Due to smooth shearing action a better surface quality is achieved by using higher rake angle inserts.

IV. CONCLUSIONS

The present work include the extensive investigational analysis of precision CNC turning processes to understand the capability of the process to generate high degree of surface flatness on Nickel surface. The experiment is carried out to explore the effect of process parameters on machinability of Nickel alloy during precision CNC turning operation. From the experimental results and subsequent Taguchi's analysis the conclusions for surface flatness value can be deduced from the study as on pure Nickel alloy in Precision CNC turning process. It is observed from the ANOVA table, there is no statistically significant factor in this experiment. Since he P-value in the ANOVA table for any input parameter is not less than 0.05, there was not statistically significant relationship between any input parameter and the response variables at the 95.0% confidence level. However, spindle speed and depth of cut, both are having much more influence on final surface integrity of machined substrates than other factors. The minimum flatness value is achieved as 2.6 µm.

ACKNOWLEDGMENT

The authors are grateful to the support of Prof. D. P. Nathe, Principal, Government Polytechnic Nashik (An Autonomous Institute of Govt. of Maharashtra) and Joint Director, Technical Education for Nashik region, India. Also thankful to Accurate Engineering Co. Pvt. Ltd., Nashik for providing the measurement facility for the study. It was not possible with the help of students named as Mahesh Bagul, Shweta Jadhav, Akshay Jagtap, Sanket Jagtap, Ankit Mali and Chetan Mali.

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