Design of experiment using Taguchi method for milling aluminum via helical ramping entering method

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Abstract—*In this paper milling parameters for aluminum alloy using high-speed steel tool are investigated. Milling is machining process where a material is cut while it's in immediate contact with a rotational tool called mill. The machine used for this type of machining is computer numerical controlled milling machine i.e. CNC mill. This machine provides simultaneous movement of the tool during cutting. Many different types of milling are available considering the different movement that machine provides. This work investigates effects of the helix ramping cutting methods such as ramping angle, ramp taper angle, helical ramp diameter, ramp clearance height and tool diameter on machining time for AL3003 aluminum alloy. For investigation effects of parameters Taguchi method in term of experimental design is applied. In investigated milling process three levels at each parameter were used.*

Keywords: Experimental design, CNC Milling, Machining Time, Taguchi Method, Helix ramping cutting

1. INTRODUCTION:

In modern production industry computer numerically controlled machines (CNC machines) are very common and they took a big part in different processes. This kind of machining became very popular in the last few decades. Production with CNC machines started in the middle of 20th century. Machining programs for CNC machine programs are written in G code. This code is processed by the use of a machine to alphanumerical ASCII language which is used to define paths of the moving parts of the machine and various other commands related to machining process [1].

Fast development of computers and lowering the prices of components made CNC machines unavoidable part of modern production systems. In this type of machining following advantages are achieved:

1) Simplified changing of production process
2) Availability to storage a large amount of programs
3) Higher dimensional accuracy of the product
4) Better control of production process

Milling is very prominent machining process in many workshops. Milling process comprises tool movement along workpiece with axis rotation in the plane perpendicular or parallel to the plane of the machined workpiece. Photographic view of the milling machine is shown in Fig – 1. When the axis is in the plane parallel to the plane of the workpiece milling is called peripheral milling and when the axis lies in the plane perpendicular to the workpiece it is called face milling. These two positions represent two main categories of milling. Some of the most common operations that are performed in milling process are:

1) Pocket milling
2) Slot milling
3) Profile milling
4) Contour milling

Considering spindle position milling are divided into two categories i.e. vertical and horizontal milling hence machines for these types of milling are called vertical and horizontal mills. Vertical milling machines categorization considering a number of axes is following:

1) 2D milling- Where machining is done in two axes along horizontal and vertical direction
2) 2.5D milling – Machining where a tool is positioned at the desired position on applicate but simultaneously control is available just along abscissa and ordinate.
3) 3D milling – In 3D machining all three axes: abscissa, ordinate and applicate are simultaneously controlled during the cutting process.
4) 4D Milling – For obtaining 4D milling during simultaneous rectilinear movement along the abscissa, ordinate, applicate and rotational movement of the machine head or table should be enabled.
5) 5D Milling- This type of milling requires simultaneous rectilinear movement along abscissa, ordinate, applicate and rotational movement of the both machine head and the machine table.
6) Multi-axis milling – Milling in more than 5 dimensions is less common and it is often call machining center which includes multiple turrets, spindles etc.

Fig - 1: Photographic view of milling machine

Adaptive milling is a process where machining operations are constantly monitored by computer and where parameters of the machining regime are adapted to current conditions during machining. This type of milling is especially useful for workpieces made with forging and casting processes. During this milling process, feed rates and speed are controlled during the cutting so that optimal forces with desired results can be obtained.

2.DESIGN OF EXPERIMENTS:

The design of the experiment is a well-known field of science which developed from statistics. This field of science found its place in many engineering applications. Many statistical methods are successfully used to investigate and draw a conclusion for different processes and phenomena. After the experiment is performed, results are obtained through various types of measurements. Two main structures are defined in the design of experiments i.e. treatment structure and design structure hence that factors must be appropriately assigned [2].

3. TAGUCHI METHODS:

Taguchi methods are used as one of the most efficient methods for obtaining processes characteristics in different fields of science. Besides many of methods used in the design of experiments, Taguchi methods found its place as one of the most popular optimization techniques. Optimization techniques are proposed by Kiefer (1985) as one of the designs of experiment types [3]. Type of experiments that use optimization techniques are used to obtain advantages such as:

1) Obtaining better product quality
2) Lowering the price of the product
3) Decreasing production times
4) Balancing the quality between product group from the same series
5) Increasing quality of the production process

The beginnings of Taguchi methods were in the field of agriculture, but when their potential was recognized then this concept was spread and successfully applied to various fields of science and especially in manufacturing engineering [4]. In Taguchi methods, so-called S/N ratio is used. When using this design experiment method this ratio should be determined and analyzed. Based on its value one can determine which factor or level of factor produces the best desirable response. Hence aforementioned three main cases are possible i.e. smaller the better as in (1), nominal the better shown in (2) and larger the better given in

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum_{i=1}^{n} y_i^2\right) \quad \text{.......................................(1)}$$

$$\frac{S}{N} = -10\log\left(\frac{\left(\bar{y}\right)^2}{S^2}\right) \quad \text{.......................................(2)}$$

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum_{i=1}^{n}\left(\frac{1}{y_i}\right)^2\right) \quad \text{.......................................(3)}$$

4. EXPERIMENTAL DESIGN:

This method allows drawing conclusions that are very reliable with less number of runs performed per experiment. In Taguchi methods, specially designed plans are used in order to obtain results with s simpler experimental setup. Taguchi methods significantly reduce the number of runs e.g. 27 experimental runs required by classical full factorial experiment is reduced to 9 for three-factor at three level each experiment. The chemical composition of investigated material is given in Table 1, while other properties can be found in Table 2. In the design of experiments, one of the main goals is to acquire as much information as possible from performed experiment [5]. Every experiment should be planned in the detail so all unnecessary costs are reduced to minimum.

For this experiment with five factors at three level each Taguchi L27 orthogonal array was chosen. Factors and factor levels are represented in Table 3.

Table 1 : Chemical composition of the Aluminum 3003

Aluminum alloy Al 3003 composition	
Cobalt (Co)	0.05 - 0.20
Hydrogen (H)	0.7
Magnesium (Mg)	1.00 - 1.50
Silicon + Iron (Si+Fe)	0.6
Zirconium (Zr)	0.1
Other (Each)	0.0 - 0.05
Others (Total)	0.0 - 0.15

Table 2 : Properties of Aluminum 3003

Property:	Value:	Unit:
Elastic Modulus	69000	N/mm^2
Poisson's Ratio	0.33	N/A
Shear Modulus	27000	N/mm^2
Mass Density	2700	kg/m^3
Tensile Strength	110.297	N/mm^2
Yield Strength	41.3613	N/mm^2
Thermal Expansion Coefficient	2.3e-005	/K
Thermal Conductivity	170	W/(m·K)
Specific Heat	1000	J/(kg·K)

Milling process with helical ramping is the desired method of tool motion in regard of lowering the produced strain that tool material is exposed to. Also, another very important parameter is the chip escaping path which is significantly improved compared to plunge entering. This entering method makes aforementioned parameters particularly evident if non-center cutting end mills are used. In this work following factors and levels are defined: ramping angle with 10, 15 and 30 degrees; ramp taper angle at 5, 10 and 15 degrees; ramp clearance height of 2,3 and 4 mm; helical ramp diameter 2.5, 3 and 4mm; tool diameter of 4, 5 and 10 mm. Predicted measuring time is obtained in seconds.

Table 3 : Values of factor levels

Level values for each factor:			
Factor:	*Level 1:*	*Level 2:*	*Level 3:*
Ramping angle	10	15	30
Ramp taper angle	5	10	15
Ramp clearance height	2	3	4
Helical ramp diamater	2.5	3	4
Cutter diameter	4	5	10

For generation and analysis of the experimental setup Minitab 17.0.1 software was used. In Table 4 factor level combinations for each run are shown.

Table 4 : Experimental setup order

Run No.	Ramping angle	Ramp taper angle	Ramp clearance height	Helical ramp diameter	Cutter diameter
1	10	5	2	2.5	4
2	10	5	2	2.5	5
3	10	5	2	2.5	10
4	10	10	3	3	4
5	10	10	3	3	5
6	10	10	3	3	10
7	10	15	4	4	4
8	10	15	4	4	5
9	10	15	4	4	10
10	15	5	3	4	4
11	15	5	3	4	5
12	15	5	3	4	10
13	15	10	4	2.5	4
14	15	10	4	2.5	5
15	15	10	4	2.5	10
16	15	15	2	3	4
17	15	15	2	3	5
18	15	15	2	3	10
19	30	5	4	3	4
20	30	5	4	3	5
21	30	5	4	3	10
22	30	10	2	4	4
23	30	10	2	4	5
24	30	10	2	4	10
25	30	15	3	2.5	4
26	30	15	3	2.5	5
27	30	15	3	2.5	10

CAM software is used as the irreplaceable tool for production purposes of various types of parts whether for simple or complex surface design [6]. In Fig – 2 generated tool path for tool diameter of 4 mm is shown. Numerical simulation is carried out with Autodesk HSM Works CAM Add-on for CAD software.

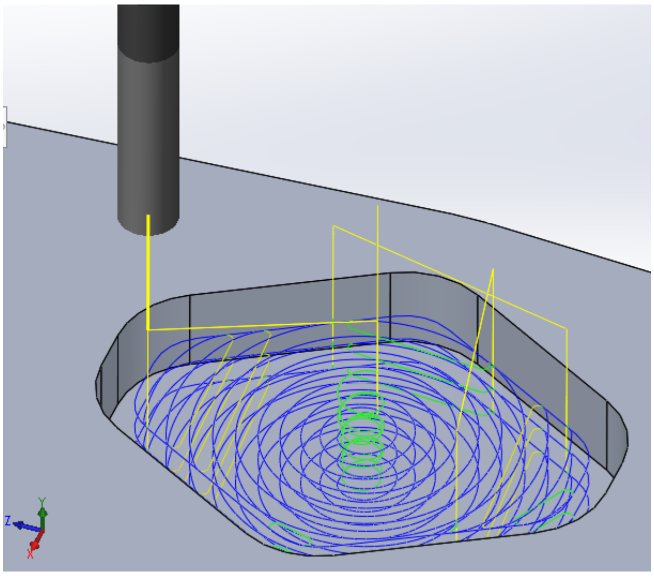

Fig - 2 : Tool path generated in CAM

In Fig – 3 stock simulation event can be seen. This verifies that there is no collision in aforementioned setup during machining process and that complete material removal is done. For every experimental run performed collision was not detected and material removal was complete.

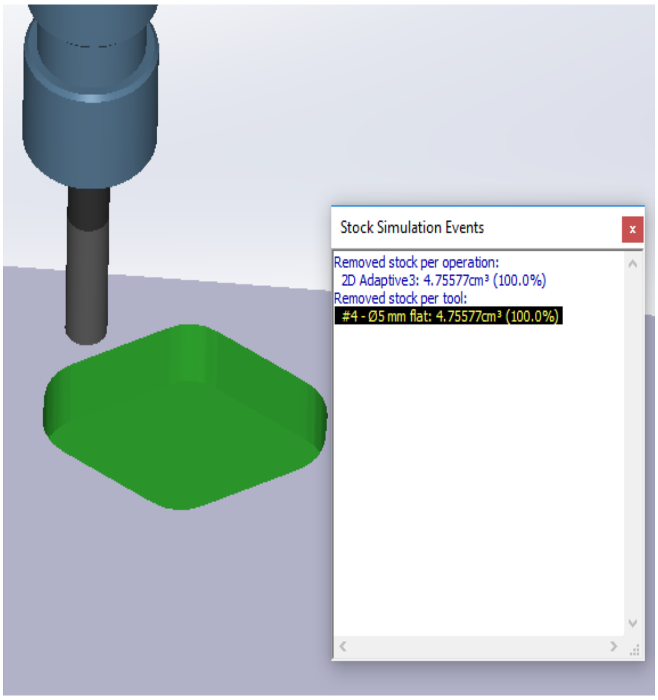

Fig - 3 : Verification of stock simulation event

Results of runs performed are shown in Table 5. S/N ratio for each experimental run was obtained for the case of S/N ratio smaller the better as can be seen in the same table.

Table 5 : Obtained results for experimental setup

Run No.	Ramping angle	Ramp taper angle	Ramp clearance height	Helical ramp diameter	Cutter diameter	Machining time	S/N ratio
1	10	5	2	2.5	4	115	-41.214
2	10	5	2	2.5	5	103	-40.257
3	10	5	2	2.5	10	79	-37.953
4	10	10	3	3	4	116	-41.289
5	10	10	3	3	5	101	-40.086
6	10	10	3	3	10	82	-38.276
7	10	15	4	4	4	118	-41.438
8	10	15	4	4	5	102	-40.172
9	10	15	4	4	10	82	-38.276
10	15	5	3	4	4	114	-41.138
11	15	5	3	4	5	99	-39.913
12	15	5	3	4	10	77	-37.73
13	15	10	4	2.5	4	113	-41.062
14	15	10	4	2.5	5	101	-40.086
15	15	10	4	2.5	10	76	-37.616
16	15	15	2	3	4	112	-40.984
17	15	15	2	3	5	96	-39.645
18	15	15	2	3	10	76	-37.616
19	30	5	4	3	4	111	-40.906
20	30	5	4	3	5	93	-39.37
21	30	5	4	3	10	76	-37.616
22	30	10	2	4	4	112	-40.984
23	30	10	2	4	5	93	-39.37
24	30	10	2	4	10	72	-37.147
25	30	15	3	2.5	4	110	-40.828
26	30	15	3	2.5	5	91	-39.181
27	30	15	3	2.5	10	71	-37.025

In this case, relevant S/N ratio is the smaller the better. Considering this ratio mean of S/N ratios for each factor on every level would be as shown in Fig – 4 and Fig-5.

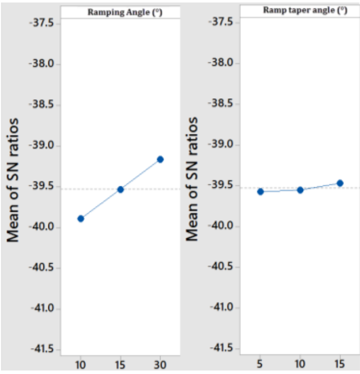

Fig - 4 : Means of S/N ratio for ramping angle and ramp taper angle

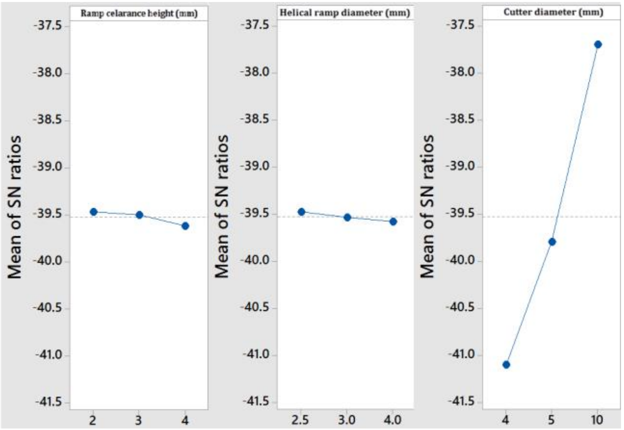

Fig - 5 : Means of S/N ratio for ramp clearance height, helical ramp diameter and cutter diameter

Delta value is shown in Table – 6, through response table setup, obtained for means in terms of ramping angle, ramp taper angle, helical ramp diameter, ramp clearance height and tool diameter.

Table 6 - Response table for means

Response Table for Means					
Level	Ramping angle	Ramp taper angle	Ramp clearance height	Helical ramp diameter	Cutter diameter
1	-39.88	-39.57	-39.46	-39.47	-41.09
2	-39.53	-39.55	-39.50	-39.53	-39.79
3	-39.16	-39.46	-39.62	-39.57	37.70
Delta	0.73	0.010	0.15	0.11	3.40
Rank	2	5	3	4	1

5. CONCLUSIONS

In milling process for aluminum alloy Al3003 five parameters i.e. ramping angle, ramp taper angle, helical ramp diameter, ramp clearance height and tool diameter was examined. Taguchi methods were used to design the experiment and for analyzing acquired data due to allowing obtaining results with far less experimental runs compared to a conventional factorial design of experiments. Factors that showed the biggest impact on machining time were tool diameter and ramping angle followed by ramp clearance height, helical ramp diameter and ramp taper angle respectively.

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