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A Systematic Approach for Identifying Turning Center Capabilities with Vertical Machining Center in Milling Operation

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Abstract**—**Conventional machining is a form of subtractive manufacturing, in which a collection of material-working processes utilizing power-driven machine tools are used to remove undesired material to achieve a desired geometry. This paper presents an approach for comparison between turning center and vertical machining center by optimization of cutting parameters at cylindrical workpieces leading to minimum surface roughness by using taguchi methodology. Aluminum alloy was taken to conduct experiments due to its unique high strength-weight ratio that is maintained at elevated temperatures and their exceptional corrosion resistance. During testing, the effects of the cutting parameters on the surface roughness were investigated. Additionally, by using taguchi methodology for each of the cutting parameters (spindle speed, depth of cut, insert diameter, and feed rate) minimum surface roughness for the process of turn-milling was determined according to the cutting parameters. A confirmation experiment demonstrates the effectiveness of taguchi method.

Keywords**—**Surface roughness, taguchi parameter design, turning center, turn-milling operations, vertical machining center.

I. Introduction

ROUND components needed to be machined on a lathe and then on a milling machine years ago. In other words, each piece had to be handled at least two times, leading to an increase in cost of efficiency and labor. Precision was also affected in that adding another process added another possibility of feature location errors. However, within the last twenty years, CNC turning machines and CNC milling machines were partially merged into turn-mill machining centers [1].

Turn-milling is a comparatively new concept in manufacturing technology in which a curved surface is milled while the work piece is being rotated around its center point. This process can be generally classified into face turn milling and periphery turn milling. This new technology opens up new ranges in the manufacturing processes [2].

Turn-milling is not particularly demanding of the machine tool, but at minimum, the process does require Y-axis motion. Workpiece rotation provides the C-axis motion that delivers the desired feed rate for the milling cutter. The fact that this change is beneficial points out how different turn-milling is from milling in general. In a more standard milling application, sending force along the tool's axis can be good. There are many reasons why a shop might want to use the turn-milling process, such as chip control and dealing with interrupted cutting. Today's users of turn-mill machines should be thinking about this style of cutting in cases where they struggle with standard turning [3]-[6].

There are certain products in the market that require turning-milling cuts (e.g. cylindrical products such as shafts). Because of the pressure of modern competition, companies tend to achieve production goals with the lowest costs and higher quality by using the turn-milling process. The turn milling process will not eliminate all quality related issues, but by using only one machine instead of two, the risk of having a quality issue is reduced. Six sigma is a well-known tool used to eliminate defects by reducing process variation. Previous research has been done on turning centers and vertical machining centers individually using Taguchi methods, a Six Sigma technique. But there is no relevant research being done using Six Sigma methods to compare vertical machining centers to turning centers. This research is the first of its kind and will help future research in this field.

In this research, end mills were used to cut the edges of the part and surface roughness was selected as the quality attribute because surface roughness is a measure of the product's technological quality that greatly influences manufacturing cost. In order to improve the product properties, fatigue strength, corrosion resistance and aesthetic appeal of the product, a reasonably good surface finish is desired. The roughness average (Ra) is the area between the roughness profile and its central line, or the integral of the absolute value of the roughness profile height over the evaluation length. Machining accuracy is realized by selected cutting operations, which have limited capability of attaining the desired surface roughness. Prior to testing, four control factors and a noise factor were selected. Testing was done using different combinations of the factors, and as a result, the optimal cutting parameters were realized. It is necessary to determine optimal cutting parameters during the designing process in order to achieve minimal expenses and minimal production time [7]-[10].

The purposes of this paper are summarized as follows:

1. To find the optimum milling operation parameters for surface roughness from turning center and vertical machining center.
2. To find out if these optimum parameters for surface roughness obtained from CNC turning center and CNC

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vertical machining center show the same surface roughness (Ra) value.

3. To identify the effect of noise parameter on the surface roughness

II. Methodology

Experimental design methods are a statistical technique that were introduced by Sir R. A. Fisher in England in the early years of 20th century and since then have been extensively studied by statisticians, but were not easy to use by practitioners [11]. In the early 1950s, Dr. Genichi Taguchi, the "father of Quality Engineering," introduced the concept of off-line quality control techniques known as Taguchi parameter design [12]. Cesarone gave a fundamental plan on areas by which design of experiments and Taguchi methods differentiate. Due to the nature of these differences, Cesarone recommends determining the ideal method which is more robust, easy and quick to find optimum results [13].

Taguchi techniques have been used widely in engineering design due to the fact that they require limited knowledge of statistics and make it easy to adopt capability [11], [14]. The complete Taguchi methods are actually comprised of three main phases, which are all intended to be conducted offline. These three phases include system design, parameter design, and tolerance design. The Taguchi parameter design is used in this study and is commonly referred to as the Taguchi method. [15]. Taguchi parameter design, which is an engineering method used for product or process design, focuses on determining the combination of parameter (factor) settings which will produce the best levels of a quality characteristic (performance measure) with minimum variation. Taguchi designs provide a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions [11]. In particular, it is recommended for analyzing metal cutting problems for finding the optimal combination of parameters [16]. Taguchi parameter design is based on the concept of factorial design [17]. Two more important tools used in parameter design are orthogonal arrays and signal-to-noise (S/N) ratios [11]. A S/N ratio is used as a measurable value instead of using the standard deviation due to the fact that as the mean decreases, the standard deviation also decreases and vice versa. In other words, the standard deviation cannot be minimized first which means the mean cannot be brought to the target. In practice, the target mean value may change during the process development. Two of the applications in which the concept of S/N ratio is useful are the improvement of quality through variability reduction and the improvement of measurement [15].

III. Experimental Design, Setup and Procedure

Fig. 1 represents the procedure done and outlines each of the steps of the present research.

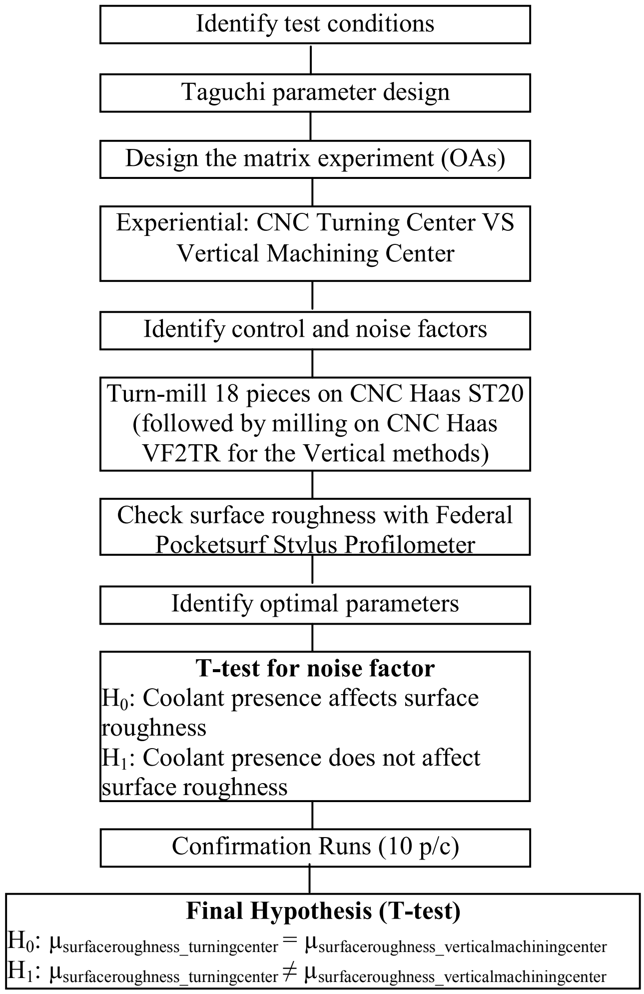

Fig. 1 Project flow chart

The cutting experiments were carried out on the CNC HAAS Turning Center (ST20, manufacturer, Fig. 2) and the CNC HAAS vertical Machining Center (model, manufacturer, Fig. 3). As discussed earlier, this research required a turn-mill operation. The selected workpiece (Fig. 4) was created in Mastercam X5, a computer aided manufacturing (CAM) software, which is best suitable for this type of manufacturing designs. It generates G&M codes which then can be imported to CNC machines. Its cylindrical shape can be turned as well as milled on both CNC machines. The workpiece is one inch in diameter and every cut was made after a length of one and half inches. The upper portion square cut was milled taking 0.625 inch as the length between opposite flat surfaces. The top circular cut was made taking 0.425 inch as the diameter. Initially, 18 turn-mill cuts were carried out on the CNC HAAS turning center.

Fig. 2 CNC HAAS Turning Center, Model ST20

Fig. 3 CNC HAAS Vertical Machining Center, Model VF2TR

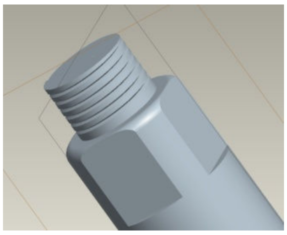

Fig. 4 3D model of selected workpiece

For the next set of experimental runs, 18 cuts were turned on the CNC turning center and then each piece was milled on the NC HAAS vertical machining center. A total of 36 experiments were conducted on both CNC machines with inner control factor arrays and noise array. The tool insert used in this experiment is four flutes, high-speed steel flat end mill. Aluminum 6161-t6511 was used for the workpiece, as its application requires good surface finish for assembly into other parts.

The significant parameters which have an effect on workpiece surface finish are scrutinized using a cause and effect diagram. All the potential factors for poor surface finish were identified and summarized in the cause and effect diagram (Fig. 5). The main cutting factors that affect surface finish are spindle speed (A), depth of cut (DOC) (B), feed rate (C), and insert diameter (D).

A. Plan of Taguchi's Orthogonal Arrays

The proper orthogonal array (Table I) is selected according to the number of total parameters accumulated from the Fig. 5. Critical issue is the level selection for each parameter, as it is required by the linear or non-linear behavior of each individual parameter against the investigated response group [18]. There are 18 basic types of standard orthogonal arrays (OA) in the Taguchi parameter design [19]. Three levels of total four parameter factors were considered. Therefore, this research selects L9 (34) orthogonal array (Table II), as described by Fowlkes and Creveling [20]. In the orthogonal array, L9 (34), "9" stands for nine sets of experiments, "3" means that each cutting parameter has three levels, and "4" indicates four cutting parameters.

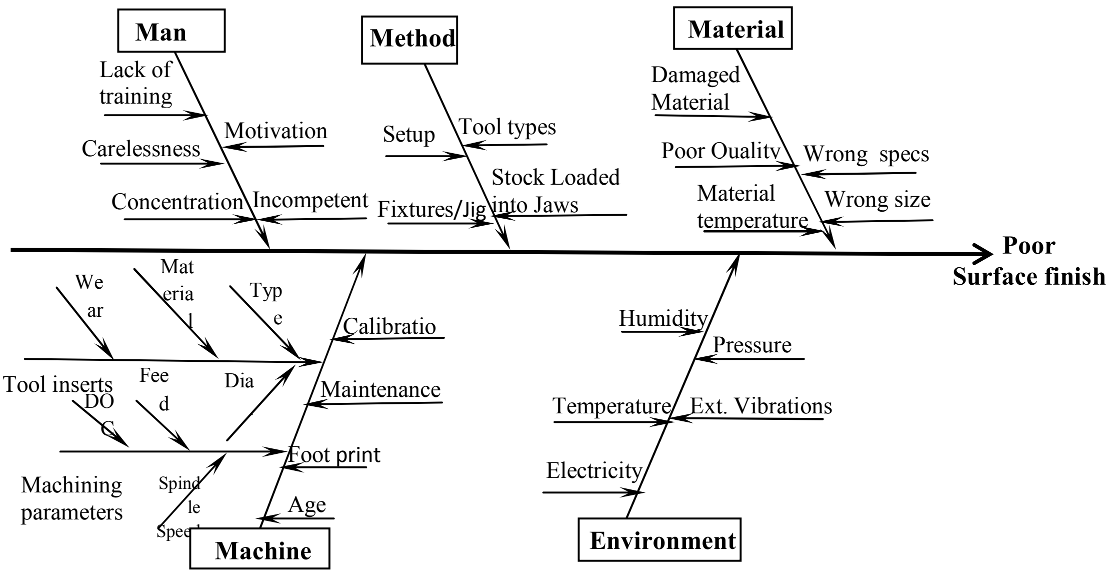

Fig. 5 Cause and Effect diagram for poor surface finish

TABLE I
TAGUCHI ORTHOGONAL ARRAY L9

Run	A	B	C	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 = Spindle speed, B= Feed rate, C=Depth of cut, D= Insert diameter

B. Select Noise Factor and Control Factor

The most significant machine parameters having a direct effect on surface roughness are feed rate, speed and depth of cut [21]-[25]. Therefore, four control parameters which are taken considering previous research are spindle speed (A), feed rate (B), depth of cut (C) and insert diameter (D). Coolant flood is considered the noise factor, as the flow of flood is not constant and is sometimes uncontrollable which affects the surface roughness of the workpiece. Four control parameters with three levels each were used in this study (Table II).

All four control parameters are the same for conducting experiments on Vertical machines to get a better comparison of these two machines. The only difference in levels is that the vertical machining center runs on high spindle speed as shown in Table III.

C. Conducting the Experiments

A controlled turning and then milling experiment was conducted on a 6061 aluminum rod (with diameter of 1 inch) to determine the relationship between control parameters and surface quality. The ST20 Turning machine has 2-axis with high-torque live tooling and a C axis which makes it possible to machine multiple features and perform secondary operations in a single setup [26].

TABLE II
TAGUCHI DESIGN PARAMETERS AND LEVELS FOR THE CNC TURNING CENTER

Parameter	Level 1	Level 2	Level 3
Control Factors (X)			
Spindle Speed, N(rev/min) (A)	1500	2000	2500
Feed Rate, f (in/min) (B)	10	20	30
Depth of cut, d(in) (C)	0.01	0.02	0.03
Insert diameter (in) (D)	1/2	3/4	5/8
Noise Factor			
Coolant Flood	YES	NO	--
Response Variable (Y)			
Surface Roughness (μin R_a)			

Yes = Use coolant, No = No coolant

TABLE III
TAGUCHI DESIGN PARAMETERS AND LEVELS FOR VERTICAL MACHINE

Parameter	Level 1	Level 2	Level 3
Control Factors (X)			
Spindle Speed, N(rev/min) (A)	2500	5000	7500
Feed Rate, f (in/min) (B)	10	20	30
Depth of cut, d(in) (C)	0.01	0.02	0.03
Tool diameter (in) (D)	1/2	3/4	1
Noise Factor			
Coolant Flood	YES	NO	--
Response Variable (Y)			
Surface Roughness (μin R_a)			

All four parameters were programmed into the MasterCam program and the workpieces were cut in order of the setup sheet (Table II for Turning Center). The tool inserts were also programmed and changed automatically by selecting the tool number. The inserts were checked for wear after each run, and since no wear was noticeable throughout the duration of the experiment, the inserts were retained for the whole set of 18 runs. The cut pieces were then taken for the surface roughness measurement test. The profilometer was calibrated before taking measurements. This process included use of the profilometer, as well as blocks, which were used to align the top surface of the workpiece vertically with the profilometer. The maximum Ra was recorded for each cut to get the clear results in analysis.

Table IV shows the Taguchi experimental design of turning center with individual sample numbers and their parameters, listed in order of orthogonal array runs and noise numbers.

The similar experiments were carried out on the Haas vertical machining center. The Haas Automation's VF-2TR vertical machining center is based on the popular Haas VF-2 VMC platform. The standard table has been replaced with a dual-axis trunnion table that provides 5-axis motion or can be used to position a workpiece at almost any angle for machining [27].

All variable parameters were run in accordance with the selected parameters (Table III). First of all, the turned cuts were carried out on the CNC turning center, as the vertical machining center is not capable of turning the workpiece. These turned cuts were given finish cuts, and then the workpiece was set up in the vertical machining center. The workpiece was set up vertically, as the machine tool cuts in the vertical direction. This also required some setup time, which is very crucial when considering mass production. All four cutting parameters were programmed into the MasterCam program and workpieces were cut in order of the setup sheet (Table III). The vertical machining center is capable of milling a workpiece at a spindle speed of 7500 rpm, which is quite high in comparison to turning center. The inserts were checked for wear after each run, and since no wear was noticeable throughout the duration of the experiment, they were retained for the whole set of 18 runs.

TABLE IV
FINAL TAGUCHI EXPERIMENTAL DESIGN

	Spindle speed	feed rate	Depth of cut	Tool diameter	Noise	Coolant flood
1	1500	10	0.01	1/2	N1	YES
					N2	NO
2	1500	20	0.02	3/4	N1	YES
					N2	NO
3	1500	30	0.03	5/8	N1	YES
					N2	NO
4	2000	10	0.02	5/8	N1	YES
					N2	NO
5	2000	20	0.03	1/2	N1	YES
					N2	NO
6	2000	30	0.01	3/4	N1	YES
					N2	NO
7	2500	10	0.03	3/4	N1	YES
					N2	NO
8	2500	20	0.01	5/8	N1	YES
					N2	NO
9	2500	30	0.02	1/2	N1	YES
					N2	NO

The following cut pieces were then taken for the surface roughness measurement test. The profilometer was calibrated before taking measurements. This process included use of blocks which were used to align the top surface of the workpiece vertically with the profilometer. The maximum Ra was recorded for each cut to get the clear results in analysis. Table V shows the Taguchi experimental design of milling center with individual sample numbers and their parameters, listed in order of orthogonal array runs and noise numbers.

IV. RESULT AND ANALYSIS

The completed orthogonal array for the CNC turning center is shown in Table VI. This shows Y-bar, i.e. surface roughness (µin Ra) of each sample, along with signal-to-noise ratio, yi is the surface roughness measurements for N1 and N2. N1 is the average of three data values when coolant flood was taken into account and N2 is the average of three data values when coolant flood was absent during cutting operation.

The results of the surface roughness effects of each sample are shown in Table VI (a). The surface roughness effects are the "lower the better" type of quality characteristics, which means the surface roughness effects should be as low as possible, and the S/N ratio should be as high as possible which makes the process better.

TABLE V
EXPERIMENTAL SETUP SHEET

Run	Spindle speed	feed rate	Depth of cut	Tool diameter	Noise	Coolant flood
1	2500	10	0.01	1/2	N1	YES
					N2	NO
2	2500	20	0.02	3/4	N1	YES
					N2	NO
3	2500	30	0.03	1	N1	YES
					N2	NO
4	5000	10	0.02	1	N1	YES
					N2	NO
5	5000	20	0.03	1/2	N1	YES
					N2	NO
6	5000	30	0.01	3/4	N1	YES
					N2	NO
7	7500	10	0.03	3/4	N1	YES
					N2	NO
8	7500	20	0.01	1	N1	YES
					N2	NO
9	7500	30	0.02	1/2	N1	YES
					N2	NO

The above combinations were computed for each of the 18 trials and the values for Turning Center and Vertical Center are shown in Table VI and Table VII, respectively.

The lower the better characteristic is shown as:

$$\frac{S}{N} = -10\log\frac{1}{n}(\sum y^2) \tag{1}$$

where $\bar{y}$ is the average of observed data, n is the number of observations, and y represents the observed data.

The surface roughness on milling cuts was measured using the Pocket Surf stylus profilometer. Three data values (1,2,3) were taken to get an accurate result of outer array. N1 is the average of three data values when coolant flood was taken into account and N2 is average of three data values when coolant flood was absent during cutting operation. The main effects for each level of each parameter on surface roughness and S/N ratio for Turning Center and Vertical Center are shown in Tables VI (a), (b) and VII (a), (b), respectively.

TABLE VI
COMPLETED ORTHOGONAL ARRAY FOR TURNING CENTER

Run	A	B	C	D	N1 1,2,3	N2 1,2,3	Outer array N1	Outer array N2	Y-bar	S/N Ratio
1	1500	10	0.01	1/2	18,20,21	21,19,18	19.7	19.3	19.7	-25.8
2	1500	20	0.02	3/4	21,22,21	24,23,24	21.3	23.7	21.3	-27.1
3	1500	30	0.03	5/8	25,29,26	20,19,24	26.7	21	26.7	-27.6
4	2000	10	0.02	5/8	29,21,24	20,22,23	24.7	21.7	24.7	-27.3
5	2000	20	0.03	1/2	18,21,24	24,23,25	21	24	21	-27.1
6	2000	30	0.01	3/4	24,23,26	18,21,23	24.3	20.7	24.3	-27.1
7	2500	10	0.03	3/4	27,23,24	27,23,26	24.7	25.3	24.7	-28
8	2500	20	0.01	5/8	21,19,17	20,19,21	19	20	19	-25.8
9	2500	30	0.02	1/2	17,15,18	24,23,18	16.7	21.7	16.7	-25.7

TABLE VI(a)
SURFACE ROUGHNESS EFFECTS

Level	A	B	C	D
1	21.9	22.6	20.5	20.4
2	22.7	21.5	21.6	23.3
3	21.2	21.8	23.8	22.2

TABLE VI(b)
S/N RATIO EFFECTS

Level	A	B	C	D
1	-26.82	-27.03	-26.23	-26.2
2	-27.15	-26.64	-26.7	-27.36
3	-26.5	-26.8	-27.54	-26.91

TABLE VII
COMPLETED ORTHOGONAL ARRAY FOR VERTICAL CENTER

Run	A	B	C	D	N1 1,2,3	N2 1,2,3	Outer array N1	Outer array N2	Y-bar	S/N Ratio
1	2500	10	0.01	1/2	22,24,25	16,18,23	23.7	19	21.3	-26.6
2	2500	20	0.02	3/4	15,21,26	22,25,19	20.7	22	21.3	-26.6
3	2500	30	0.03	1	18,16,23	18,23,26	19	22.3	20.7	-26.3
4	5000	10	0.02	1	20,20,19	25,23,24	19.7	24	21.8	-26.8
5	5000	20	0.03	1/2	15,25,26	17,23,21	22	20.3	21.2	-26.5
6	5000	30	0.01	3/4	18,20,19	20,24,28	19	24	21.5	-26.7
7	7500	10	0.03	3/4	17,14,18	20,21,22	16.3	21	18.7	-25.5
8	7500	20	0.01	1	18,18,19	20,16,21	18.3	19	18.7	-25.4
9	7500	30	0.02	1/2	16,15,18	20,17,14	16.3	17	16.7	-24.4

TABLE VII(a)
SURFACE ROUGHNESS EFFECTS

Level	A	B	C	D
1	21.1	20.6	20.5	19.7
2	21.5	20.4	19.9	20.5
3	18	19.6	20.2	20.4

TABLE VII(b)
S/N RATIO EFFECTS

Level	A	B	C	D
1	-26.52	-26.32	-26.25	-25.86
2	-26.68	-26.18	-25.95	-26.26
3	-25.12	-25.83	-26.11	-26.19

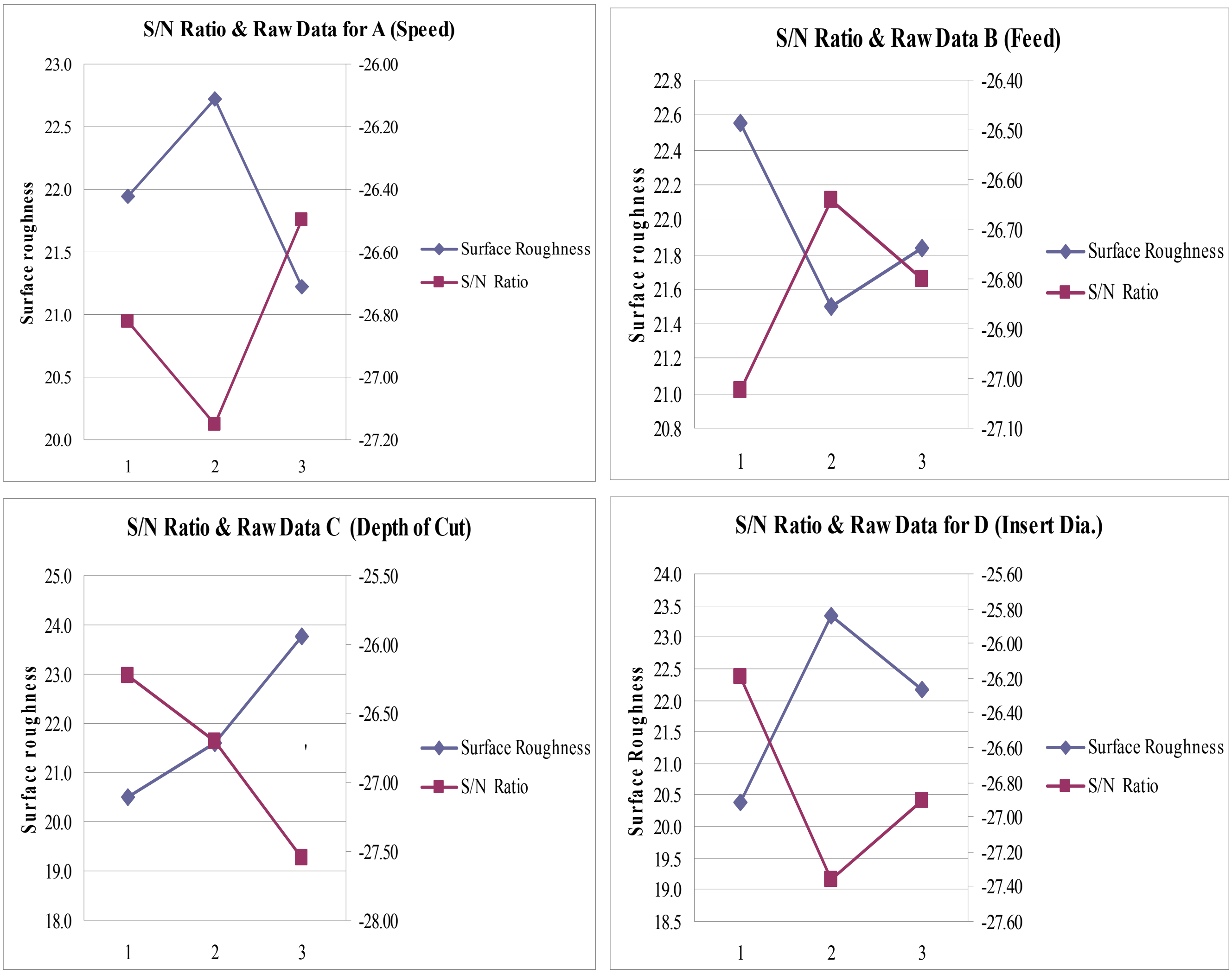

Fig. 6 Effects of all four parameters on surface roughness and S/N ratio for Turning Center

Since we are looking for the mean and variance of the surface roughness values to be as small as possible, the ideal S/N effects should be as large as possible. This can be show graphically as well. Figs. 6 and 7 show plot of the response and S/N ratio effects from Turning Center and Vertical center, respectively. These graphs tell the level to be chosen for the ideal cutting parameters (the level with the highest point on the graph), as well as the relative effect each parameter has on the S/N ratio (the general slope of the line). The arrows in the graphs indicate the levels at which the S/N ratio and ¯Ra effects are at their optimal magnitudes; that is, the S/N ratio effect is at its highest magnitude, and the ¯Ra effect is at its lowest magnitude. The surface roughness on milling cuts was measured using a Pocket Surf stylus profilometer. Three data values were taken for each sample in order to create a fairly accurate average result.

A. Test for Equal Variances for Coolant ON and Coolant OFF

The effects of the noise factor on the cutting parameters can be checked by performing a t-test to determine the validity of these effects on the outcome. A hypothesis is constructed with the null hypothesis being defined as no difference in cutting performance by turning the coolant flood on and off. The alternate hypothesis states that there is a difference in cutting performance as a result of turning the coolant flood on and off. The t-test for coolant power for Turning Center and Vertical Center is shown in Tables VIII and IX, respectively.

H_0: Coolant presence does not affect surface roughness

H_1: Coolant presence does affect surface roughness

For Turning Center, the t-value for coolant on/off is 0.16, which is smaller than the critical value (2.921), so we can fail to reject the null hypothesis. This means that a statistically significant difference could not be detected. Hence, coolant flood does not affect the surface roughness.

For Vertical Center, the t-value for coolant on/off for Vertical Center is 1.342, which is less than the critical value of 2.921, so we fail to reject the null hypothesis. This means that a statistically significant difference could not be detected between them. Hence, coolant flood does not affect the surface roughness.

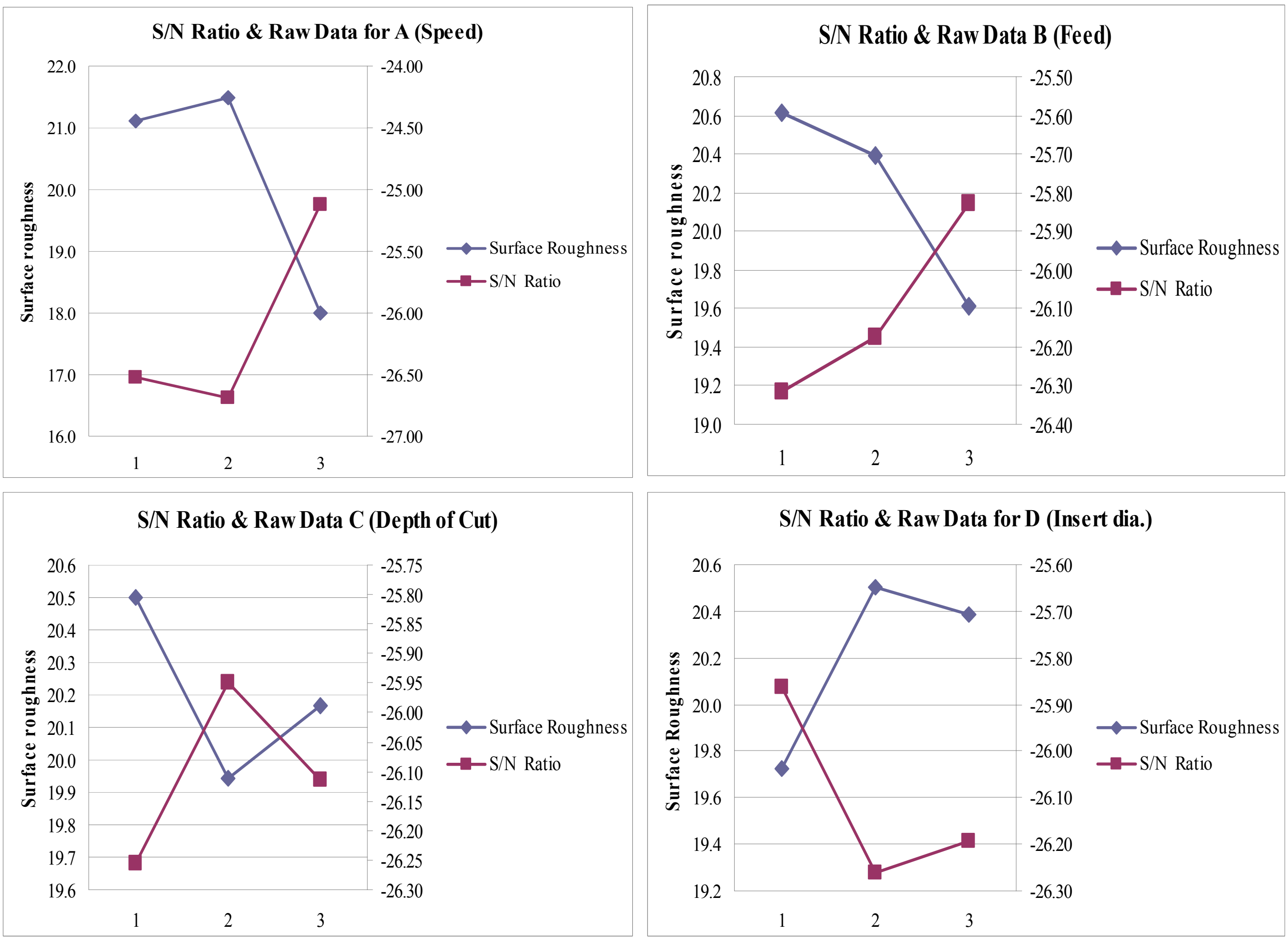

Fig. 7 Effects of all four parameters on surface roughness and S/N ratio for Vertical Center

TABLE VIII
T-TEST FOR COOLANT POWER FOR TURNING CENTER

T-test for coolant	
Average (coolant) =	**22.0**
Average (No coolant) =	**21.926**
Std Dev (coolant) =	**3.2745**
Std Dev (No coolant) =	**1.9985**
SE(two groups) =	**1.2787**
t-value =	**0.058**
Degree of Freedom =	**16**
Critical t value (alpha = 0.01)	**2.921**

TABLE IX
T-TEST FOR COOLANT POWER FOR VERTICAL CENTER

T-test for coolant	
Average (coolant) =	**19.444**
Average (No coolant) =	**20.963**
Std Dev (coolant) =	**2.420**
Std Dev (No coolant) =	**2.377**
SE(two groups) =	**1.130**
T-value =	**1.342**
Degree of Freedom =	**16**
Critical t value (alpha = 0.01)	**2.921**

B. Determining the Optima Parameters

As the result shown in Tables VI (a) and (b), the optimal parameters for machining aluminum alloys are as follows; a spindle speed of 2500 rpm, an optimal feed rate of 20 ipr, an optimal depth of cut of 0.01 inch and a tool insert diameter of ½ inch. Therefore, the best combination is A3-B2-C1-D1 (high cutting speed, low feed rate, low depth of cut and 1/2 inch HSS flat end mill insert).

For Vertical Center, as shown in Tables VII (a) and (b), the optimal parameters for machining aluminum alloys are as follows: a spindle speed of 7500 rpm, an optimal feed rate of 30 ipr, an optimal depth of cut of 0.02 inch, and a tool insert diameter of ½ inch. Therefore, the best combination is A3-B3-C2-D1. These ideal combinations would be verified by conducting confirmation run.

C. Confirmation runs

The objective of the confirmation run was to determine that the selected control parameter values would produce better surface finishes than those produced in the first part of the experiment.

TABLE X
CONFIRMATION RUNS FOR TURNING CENTER

Run #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Surface data	17	16	17	19	16	18	17	15	18	15
Mean =	16.800		Z-value (99%) =		**2.575**		Upper CI =		17.870	
St dev=	1.032		St dev(n) =		0.420			Lower CI = 15.730		

TABLE XI
CONFIRMATION RUNS FOR VERTICAL CENTER

Run #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Surface data	18	18	23	24	16	16	19	19	16	19
Mean =	18.800			Z-value (99%) =		**2.575**		Upper CI =		21.060
St dev=	2.780			St dev(n) =		0.880		Lower CI =		16.540

To create this comparison, the researchers compared the surface roughness mean of products produced using the selected control parameter values to the surface roughness mean of products produced in the first part of the experiment, which are found in Table X. A sample of 10 workpieces of the same material and dimensions described earlier was turn-milled using the selected control parameter values on the CNC turning center. The surface roughness was then measured using the setup described earlier. The response variable used in the confirmation run was the mean Ra, in μin, of measurements taken across the length of the cut, as recommended by [28]. Table X shows 10 confirmation runs obtained from surface roughness test taking 99% confidence intervals for the mean Ra and respective confidence intervals to verify the predicted optima.

$$\text{Predicted Ra} = \mu A3 + \mu B2 + \mu C1 + \mu D1 - 3\ \mu\text{total} = 17.72\ \mu\text{in}$$

Based on these results, it can be concluded with 99% confidence that by turn-milling samples using the setup described in this study and the parameters indicated in Table IV, the resulting average surface roughness (Ra) will range from 15.73 to 17.87 μin and the predicted optima of 17.72 μin is within the confidence interval.

For Vertical Center, sample of 10 workpieces of the same material and dimensions described earlier was turned on the turning center and then milled on the vertical machining center using the selected control parameter values. The surface roughness was then measured using the setup described earlier. Table XI shows 10 confirmation runs obtained from the surface roughness test taking 99% confidence intervals for the mean Ra and respective confidence intervals to verify the predicted optima.

$$\text{Predicted Ra} = \mu A3 + \mu B3 + \mu C2 + \mu D1 - 3\ \mu\text{total} = 16.67\ \mu\text{in.}$$

Based on the above results, it can be concluded with 99% confidence that by turn-milling samples using the setup described in this study and the parameters indicated in Table V, the resulting average surface roughness (Ra) will range from 16.54 to 21.06 μin and the predicted optima of 16.67 μin is within the confidence interval.

V. FINAL HYPOTHESIS

A statistical test for equal variances for the turning center and the vertical machining center is performed. In this case, the null hypothesis is defined as the mean of the response variable (Y), i.e. average surface roughness, obtained from confirmation runs on the work piece from the turning center as well as the vertical machining center is the same, whereas the alternate hypothesis, H1, contradicts this assumption by saying that the surface roughness on the workpieces from both machines has huge variations. Table XII shows C1 and C2 which represent surface roughness data collected from confirmation runs. C1 is Confirmation runs data obtained from turning center. And C2 is Confirmation runs data obtained from vertical machining center. The t-test is conducted with α = 0.05 with the following hppothesis:

H_0: $\mu_{C2} = \mu_{C2}$

H_1: $\mu_{C2} \neq \mu_{C2}$

As shown in Table XIII, taking a 95% confidence interval P-value is greater than 0.05 and the Null Hypothesis cannot be rejected. This means that means are under the 95% confidence interval and a statistically significant difference could not be detected between the surface roughnesses of workpieces from both CNC machines.

TABLE XII
COMPARISON OF CONFIRMATION RUNS FROM TURNING CENTER AND VERTICAL MACHINING CENTER

C1	**C2**
17	18
16	18
17	23
19	24
16	16
18	16
17	19
15	19
18	16
15	19

TABLE XIII
TWO-SAMPLE T TEST FOR C1 VS C2

	C1	C2
N	10	10
Mean	18.80	16.80
Standard Deviation	2.78	0.88
SE Mean	1.32	0.42
95% CI	(-0.120, 4.120)	
T-Value	2.06	
P-Value	0.062	

VI. CONCLUSION

This research looked into various aspects of CNC machines, cutting operations and quality attributes. Taguchi parameter design can provide a systematic procedure that can effectively and efficiently identify the optimum surface roughness. It reduces process variability for industries by using a small number of experimental runs and has a low cost. This process was applied using a set of control and noise parameters and a response variable of surface roughness. This study used the L9 (34) orthogonal array for two CNC machines and was conducted taking 36 experimental runs on both machines. After conducting the runs, the optimal cutting parameters used in the confirmation runs were determined. The results from the confirmation runs led to the conclusion that the selected parameter values produced a predicted surface roughness, and the results were inside the 99% confidence interval. The final hypothesis mean values were inside the 95% confidence interval.

From the above results, it can be concluded that when cutting cylindrical workpieces made of aluminum alloys, both the turning cuts and the milling cuts can be carried out using the turning center with similar surface finish. Thus, higher production could be achieved by maintaining required surface finish and could save another operator cost and other maintenance expenses.

Further research could be carried out by comparing different cutting processes or grinding, taking different parameters and noise factors into account or considering different cutting workpiece material.

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