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Investigation of the effect of the position of the cutting tool tip on the geometric tolerances and surface roughness in turning process

Tornalama işleminde kesici ucu pozisyonunun geometrik toleranslar ve yüzey pürüzlülüğüne etkisinin araştırılması

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Investigation of the Effect of the Position of the Cutting Tool Tip on the Geometric Tolerances and Surface Roughness in Turning Process

Highlights

- *The results figured out that the height of the cutting tool affected the geometries of the machined surface*
- *The rate of the effects is 1.37% on the surface roughness, 10.89% on the circularity deviation and 4.49% on the cylindricity deviation.*
- *The H:+0.5 lead to have a positive impact on surface roughness for increasing of the feed rate and the radius of the tip.*
- *The H:+0.5 provided to decrease the cylindricity deviation while rising of the feed rate.*

Graphical Abstract

In this study, turning tests were carried out to investigate the effects of the height of the cutter's tip from the machined workpiece axis. AISI 304 stainless steel material was turned on a CNC lathe using a toolholder with negative backward rake angle and SNMG coded carbide inserts. Surface roughness, circularity and cylindricity were checked on the machined surfaces.

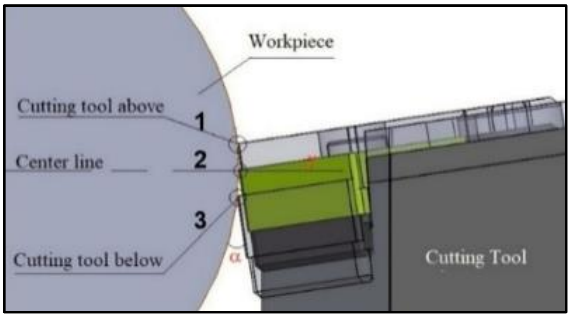

Figure. Position of the cutting tool relative to the workpiece axis

Aim

Normally, cutting tools are directly used by assembling on the CNC turning machines. The position of the tool is not controlled relative to the centre of the work piece. It is assumed that the cutting tools are manufactured in standard sizes. However, the cutting tool composed of many parts, such as insert, shim and holder, etc. These parts can be manufactured by many firms in universal tolerances.

Design & Methodology

The inserts were tested for three levels, such as, at the work piece axis (0 mm), above of the work piece axis (+0.5 mm) and below of the work piece axis (-0.5 mm). In the experiments, three different cutting speeds (100, 150, and 225 m/min), three different feed rates (0.15, 0.25 and 0.35 mm/rev), three different depths of cut (0.8, 1.3 and 2 mm) and two different insert radius (0.4 and 0.8 mm) were preferred for the cutting parameters. L36 model, which is an option in Taguchi method, were selected to perform the tests.

Originality

In the literature review examined, no similar study was found on CNC lathes.

Findings

The rate of the effects is 1.37% on the surface roughness, 10.89% on the circularity deviation and 4.49% on the cylindricity deviation.

Conclusion

The results revealed that the position of the insert relative to the workpiece axis affects the machined surface geometries.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Investigation of the Effect of the Position of the Cutting Tool Tip on the Geometric Tolerances and Surface Roughness in Turning Process

Araştırma Makalesi / Research Article

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ABSTRACT

Normally, cutting tool tools are directly used by assembling on the CNC turning machines. The position of the tool is not controlled relative to the centre of the work piece. It is assumed that the cutting tools are manufactured in standard sizes. However, the cutting tools composed of many parts, such as insert, shim and holder, etc. Many companies can manufacture these parts in universal tolerances. In this study, turning tests were carried out to investigate the effects of the height of the insert from the machined workpiece axis. AISI 304 stainless steel material was turned on a CNC lathe using a carbide cutting tool with a negative backward rake angle. The cutting tool were tested for three levels, such as, at the workpiece axis (0.0 mm), above of the workpiece axis (+0.5 mm) and below of the work piece axis (-0.5 mm). In the experiments, three different cutting speeds (100, 150, and 225 m/min), three different feed rates (0.15, 0.25 and 0.35 mm/rev), three different depths of cut (0.8, 1.3 and 2 mm) and two different insert radius (0.4 and 0.8 mm) were preferred for the cutting parameters. L36 model, which is an option in Taguchi method, were selected to perform the tests. Surface roughness, circularity and cylindricity on the machined surfaceses were controlled. The results were evaluated by Taguchi and ANOVA analyses. The results figured out that the height of the cutting tool affected the geometries of the machined surface. The rate of the effects is 1.37% on the surface roughness, 10.89% on the circularity deviation and 4.49% on the cylindricity deviation. The H:+0.5 lead to have a positive impact on surface roughness and the cylindricity deviation.

Keywords: Turning, cutting tools, setting tool, roundness, cylindricity, taguchi

Tornalama İşleminde Kesici Ucu Pozisyonunun Geometrik Toleranslar ve Yüzey Pürüzlülüğüne Etkisinin Araştırılması

ÖZ

Kesici takımlar genellikle CNC torna tezgahlarında doğrudan bağlanarak kullanılır. Takımın iş parçasının merkezine göre konumu kontrol edilmez. Kesici takımların standart ölçülerde üretildiği varsayılır. Ancak kesici takımlar, uç, ayar parçası ve tutucu gibi birçok parçadan oluşur. Birçok firma bu parçaları evrensel toleranslarda imalatını yapmaya çalışmaktadır. Bu çalışmada, kesici ucun işlenmiş iş parçası ekseninden yüksekliğinin etkilerini incelemek için tornalama deneyleri yapılmıştır. AISI 304 paslanmaz çelik malzeme, negatif talaş açısına sahip karbür kesici takımlar kullanılarak bir CNC torna tezgahında tornalanmıştır. Kesici takımlar, iş parçası ekseninde (0.0 mm), iş parçası ekseninin üstünde (+0.5 mm) ve iş parçası ekseninin altında (-0.5 mm) olmak üzere üç seviyede test edilmiştir. Deneylerde kesme parametreleri için üç farklı kesme hızı (100, 150 ve 225 m/dak), üç farklı ilerleme hızı (0.15, 0.25 ve 0.35 mm/dev), üç farklı kesme derinliği (0.8, 1.3 ve 2 mm) ve iki farklı kesici uç yarıçapı (0.4 ve 0.8 mm) tercih edilmiştir. Testler için Taguchi yönteminde bir seçenek olan L36 modeli seçilmiştir. İşlenen yüzeylerde yüzey pürüzlülüğü, dairesellik ve silindiriklik kontrol edilmiştir. Sonuçlar Taguchi ve ANOVA analizleri ile değerlendirilmiştir. Sonuçlar, kesici takımın yüksekliğinin işlenen yüzeyin geometrisini etkilediğini ortaya koymuştur. Etki oranları, yüzey pürüzlülüğü üzerinde %1.37, dairesellik sapması üzerinde %10.89 ve silindiriklik sapması üzerinde %4.49'dur. H:+0.5 yüksekliğinin, yüzey pürüzlülüğü ve silindiriklik üzerinde olumlu bir etkiye sahip olduğu tespit edilmiştir.

Anahtar Kelimeler: Tornalama, kesici takımlar, takım ayarı, dairesellik, silindirilik, taguchi.

1. INTRODUCTION

It is normally known that cylindrical parts can be processed on a lathe with rotational movement. The chip removal process is influenced by many factors. For example, tool life, cutting parameters, should be taken into account in machining process [1-2]. There are many studies, which have been doing to clarify the cutting parameters and cutting tools geometries that affect turning process, in the literature. Generally, it is emphasised that cutting speed is very important for tool life and feed rate is main effect on surface roughness [3-4]. The cutting forces, which occurred ordinarily in turning process are affected from the modified cutting parameters. Because of the rising cutting forces the tool

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life and the machining process get badly [5]. It is put forward that rake angle and clearance angle affect cutting performance and they are major elements for cutting tool geometries [6]. Generally, the cutting tools that are used in turning process are usually designed with two type rake angles such as, positive and negative [7]. Hence, the tools and turning operations are directly affected from negative and positive tools geometries. The negative cutting tools are more durable than the positive rake angle cutting tools in turning with difficult conditions [8]. But, the negative cutting tools leads to generate larger cutting forces than positive cutting tools [9]. It is not forgotten that the higher cutting force means more energy requirement in a machining process [10]. By the way, it is recommended that the cutting tools should be set on the centre of machined parts when a classical lathe machine is used to perform any turning processes [11]. However, the cutting tools are assembled without any adjustments and controls on the CNC lathe machine tools. As, it is expected that the used cutting tools on CNC machine are manufactured in standard sizes. Actually, the small differences between the cutting tip and work piece axis will change the rake angle (γ) and the clearance angle (α). In addition, the impact of the setting depends on diameter of the machined work piece. The cutting angles for a negative cutting tools are shown in Fig 1 that demonstrates a turning process.

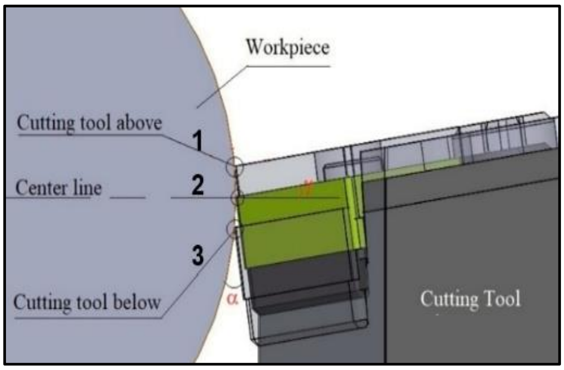
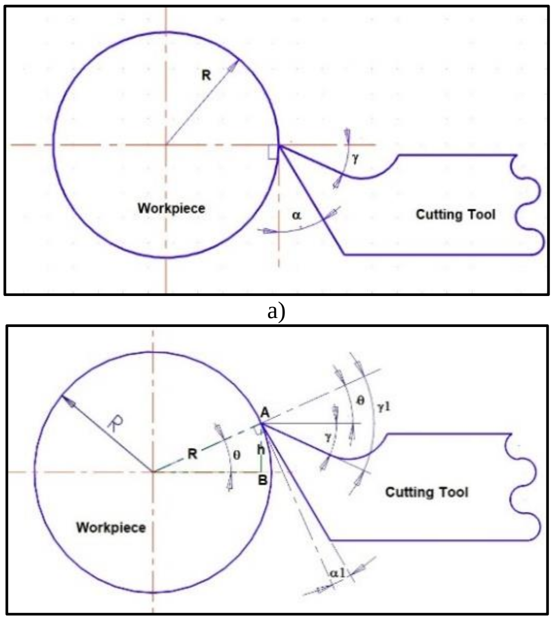


Figure 1. The variation of the rake (γ) and clearance angle (α) according to the cutting tool position

The fig 1 indicates three levels of the cutting tool's tip according to work piece axis. In the first level (1), the tip is above the axis of the work piece. In the second level (2), the tip is at the axis of the work piece. In the last level (3), the tip is below of the axis of the work piece. Yet, there are no enough studies which, figure out the effects of the adjusted cutting tool height on machined surface in the literature. For example, in a paper [12], a mathematical model was presented to calculate the deviations of the cutting angles for a positive cutting tool (Fig 2.a and Fig 2.b). Typical equations, such as 1, 2 and 3, are given below. The mathematical expressions put forward that the cutter angles are certainly altered by the cutter tip location. When the tip of the cutter is above the centre of the part, the rake angle increases, but the clearance angle decreases. These options that the modified cutting angles will affect the metal removal performance and the geometric tolerances on the machined surfaces.

A few studies about the height of the cutting tools in tuning operations were done in the literature. However, it is seen that they are not directly related to the effecting of the placed cutting tools on the turned surfaces.



a)

b)

Figure 2. A positive cutting tool locations from the work piece centre, a) At the centre, b) above the centre [11]

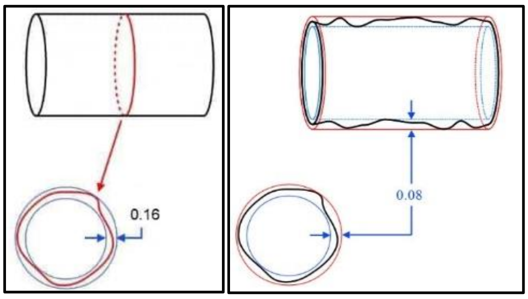
$$\sin\theta = (h/R) \text{ and } \theta = \sin^{-1}(h / R) \quad (1)$$

$$\gamma 1 = \gamma + \theta \text{ or } \gamma 1 = \gamma + \sin^{-1}(h / R) \quad (2)$$

$$\alpha 1 = \alpha - \theta \text{ or } \alpha 1 = \alpha - \sin^{-1}(h / R) \quad (3)$$

where symbols:
θ = Angle from the cutting tool's tip to centre of the work piece,
γ = Normal rake angle of the cutting tool,
$\gamma 1$ = New rake angle of the cutting tool,
α = Normal clearance angle of the cutting tool
$\alpha 1$ = New clearance angle of the cutting tool
h = height of deviation from centre of the work piece,
R = Radius of the work piece,

They usually include apparatuses, which used to adjust the cutting tool tip to the centre of the work piece [13-15]. The effects of the tool tip that is not at the centre of the parts on the machined surface is not investigated in these papers. On the other hand, any part is continuously not manufactured in the same tolerances by using any machining methods, e.g. turning [16]. The machining factors, such as, material, cutting tools and machine tools, lead to change values of the machining tolerances. In manufacturing industries, surface roughness and geometric tolerances e.g. circularity and cylindiricty, are very important criteria to be accepted of the machined parts. It is actually impossible to have a perfect circular and cylindrical shape in turning methods [17]. The circularity, which is called Roundness, is a deviation on the circular surface [18]. Similarly, the cylindricity is a deviation on the cylindrical surface [19-21]. Examples for circularity and cylindricity were given in Fig 3 [22]. Normally, to measure the circularity, a circular movement must be done around the machined surface. For instance, 0.16 mm, given in Fig 3.a, shows the circular error on the machined surface. But, to determine the cylindricity, all turned surface must be checked thorougly. For example, 0.08 mm, is illustrated in Fig 3.b, presents a cylindrical error on the turned surface.



a) b)

Figure 3. Faults on the machined surface a) Circularity b) cylindricity [22]

Generally, the cutting tools that used in turning process, consists of several spare parts, for example insert, shim (pad for the insert) and holder (Fig 4). Normally, it is assumed that the spare parts could be manufactured with the same tolerances. However, the realization of this is not possible because of some factors, such as the manufacturing conditions and the customer demands over the wold. Hence, a variety of the tolerances on the spare parts might affect the used cutting tools height from the axis of the turned part. Further, the manufactured tolerances of the ATC, Automatic Tool Changer, or any apparatus used on the CNC turning machine tools, can affect for holding the tool precisely too.

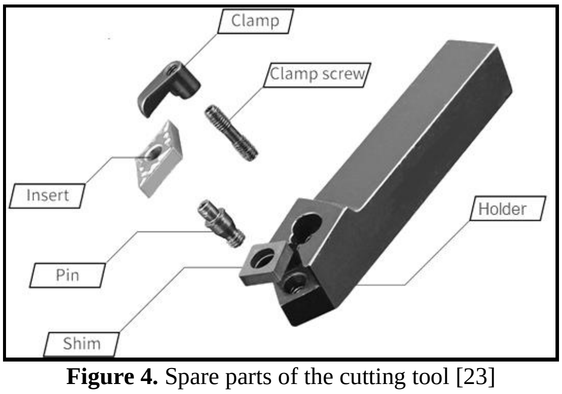


Figure 4. Spare parts of the cutting tool [23]

In this study, an experimental study was carried out to evaluate the effect of the position difference of the cutting tool relative to the workpiece axis on machining tolerances. AISI 304 material was machined on a CNC lathe using coated carbide inserts connected to a tool holder with a negative backward rake angle. The parts of the used cutting tools, such as the insert, the shim and the holder were individually checked for the dimensional tolerances. Moreover, the experiments, which were designed with Taguchi method, were carried out. The impacts of the cutting parameters and the cutter placed off the axis of the work piece on geometric tolerances of the turned surface were investigated by using Taguchi and ANOVA analysis.

2. MATERIAL and METHOD

2.1. Experimental Setup

A CNC lathe was used in this experimental works. The location of the cutting tool tip and workpiece axis was directly determined with a portable measurement device, called CMMArm, on the CNC lathe (Fig 5). According to the measured values, several metal sheets, in certain thicknesses, were prepared to adjust the height of the cutting tool tip to the centre of the test part.

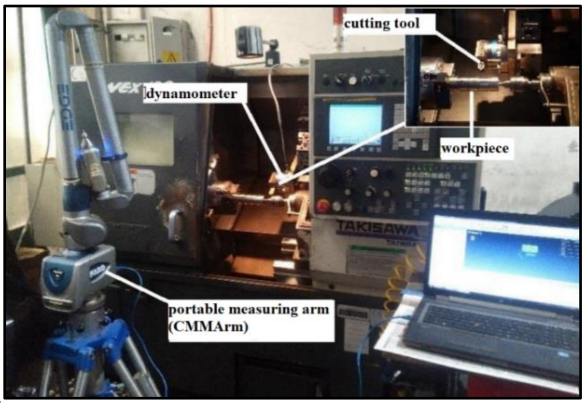


Figure 5. CNC lathe and portable measuring arm

2.2. Cutting Tools and Test Parts

In this study, AISI 304 Stainless steel was machined using carbide cutting tools and a toolholder with a negative backward rake angle in the turning process. The chemical composition and the mechanical properties for material of the work pieces (Fig 6) were given in Table 1 and 2. TSDNN2020K12 tool holder and SNMG inserts were preferred to machine the test material. The Cutting tools were coated for three layers that are TiCN/Al2O3/TiN respectively. Some specifications of the inserts and tool holder were presented by Table 3.

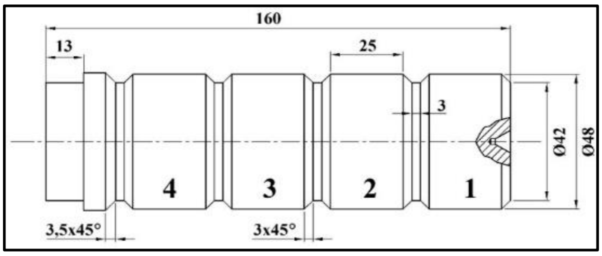


Figure 6. The work piece geometry used in the tests [24]

The height tolerances of the cutting tools' parts were controlled with a CMM machines and compared with the values of the published products catalogue. The measurements pointed that a total upper deviation of the parts was nearly 0.44 mm. It means that the cutting tools may be displaced in 0.44 mm from the axis workpiece on the CNC lathe.

Table 1. Chemical composition of AISI 304 Material

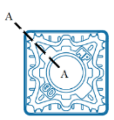
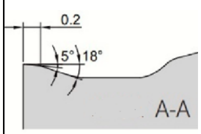
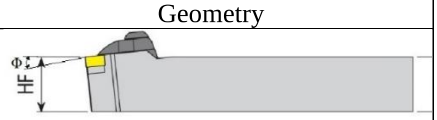
C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Al%	Cu%	Nb%	Ti%	V%	Fe%
0.059	0.375	1.499	0.034	0.006	18.63	0.425	8.84	0.002	1.130	0.0147	0.003	0.0821	68.161

Table 2. Mechanical properties of AISI 304 Material

Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Hardness (BHN)
383	644	52	189

So, the 0.5 mm was accepted as a test parameter for the height of the cutting tool in this study.
As seen in Table 3, the insert angles indicate a positive rake angle.
However, a toolholder with a 7° negative back rake angle alters these angles. The modified angles and the changes in the angles, depending on the position of the cutting tool tip relative to the workpiece axis, are shown in Fig 7 and presented in Table 4.

Table 3. Specifications of the insert and tool holder [25]

Insert			
Code	Form	Geometry	Nose radius
SNMG1204			0.4 0.8
Holder			
Code	Geometry		
TSDNN2020K12	 Φ= 7º H = HF = 20 mm		

Considering the angles determined in Table 4, it was understood that the angle (a) of the insert with a width of 0.2 mm was negative. It was determined that the angle (b) in the second part continued to be positive. Considering the experimental parameters, it was understood that the insert would cut with a negative rake angle at a feed rate of 0.15 mm/rev. At feed rates of 0.25 mm/rev and 0.35 mm/rev, it was observed that the insert would cut with negative (a) and positive (b) rake angles.

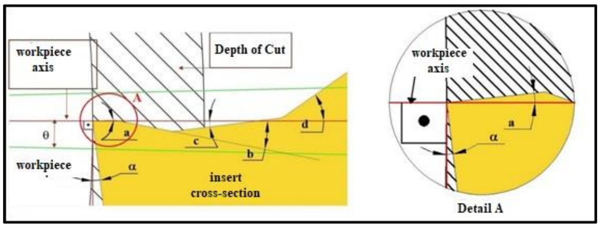


Figure 7. Angles of the insert

Table 4. Modified angles of the insert

Depth of cut (mm)	Tool holder height (mm)	α°	a°	b°	c°	d°
0.8	-0.5	8.23	-3.23	9.77	-8.23	-36.23
	0	7.00	-2.00	11.00	-7.00	-35.00
	+0.5	5.77	-0.77	12.23	-5.77	-33.77
1.3	-0.5	8.26	-3.26	9.74	-8.26	-36.26
	0	7.00	-2.00	11.00	-7.00	-35.00
	+0.5	5.74	-0.74	12.26	-5.74	-33.74
2	-0.5	8.30	-3.30	9.70	-8.30	-36.30
	0	7.00	-2.00	11.00	-7.00	-35.00
	+0.5	5.70	-0.70	12.30	-5.70	-33.70

2.3. Taguchi Method and ANOVA

It is known that the classical experimental works are high costly, because of that a lot of tests have to do for each parameters. The cutting parameters used in this work are given in Table 5. The parameters are nose radius (Rd: mm), cutting speed (V:mm/min), feed rate
(F: mm/rev) , depth of cut (ap: mm) and tool tip height (h:mm).

Table 5. Cutting Parameters

Rd (mm)	V (m/min)	F (mm/rev)	Ap (mm)	H (mm)
0.4	100	0.15	0.8	-0.5
0.8	150	0.25	1.3	0.0
	225	0.35	2	+0.5

Normally, 162 (2*3*3*3*3) tests had to be done for the parameters. Taguchi method was preferred to reduce the cost of the experiments [26]. Moreover, it is known that Taguchi and ANOVA, which provide to evaluate the effect of the cutting parameters easily, are widely used in the world [27-31]. Thus, the experiments were designed by Taguchi method. The factors and levels of the Taguchi model are given in Table 6. Taguchi mixed L36 (2^1 3^4) model tells 36 tests enough to design of these experiments. Consequently, the values of the surface roughness, circularity and cylindricity obtained from the tests that designed with L36 Taguchi model, shown in Table 7. "smaller is better" that is one of the techniques in taguchi method was performed to analyse the test results. Graphs for S/N ratios of factors were plotted. In addition, ANOVA method was applied to evaluate the contribute (%) for the effect values of the used factors.

Table 6. Taguchi L_{36} factors and levels

Factor	Level 1	Level 2	Level 3
Rd	0.4	0.8	-
V	100	150	225
F	0.15	0.25	0.35
Ap	0.8	1.3	2
H	-0.5	0.0	+0.5

Table 7. Design of Experiments for Taguchi L_{36}

Design of Experiments in Taguchi L36						Test parameters				
Exp. No.	A	B	C	D	E	Rd (mm)	V (m/min)	F (mm/rev)	Ap (mm)	H (mm)
1	1	1	1	1	1	0.4	100	0.15	0.8	-0.5
2	1	2	2	2	2	0.4	150	0.25	1.3	0.0
3	1	3	3	3	3	0.4	225	0.35	2	+0.5
4	1	1	1	1	1	0.4	100	0.15	0.8	-0,5
5	1	2	2	2	2	0.4	150	0.25	1.3	0.0
6	1	3	3	3	3	0.4	225	0.35	2	+0.5
7	1	1	1	2	3	0.4	100	0.15	1.3	+0.5
8	1	2	2	3	1	0.4	150	0.25	2	-0.5
9	1	3	3	1	2	0.4	225	0.35	0.8	0.0
10	1	1	1	3	2	0.4	100	0.15	2	0.0
11	1	2	2	1	3	0.4	150	0.25	0.8	+0.5
12	1	3	3	2	1	0.4	225	0.35	1,3	-0.5
13	1	1	2	3	1	0.4	100	0.25	2	-0.5
14	1	2	3	1	2	0.4	150	0.35	0.8	0.0
15	1	3	1	2	3	0.4	225	0.15	1.3	+0,5
16	1	1	2	3	2	0.4	100	0.25	2	0.0
17	1	2	3	1	3	0.4	150	0.35	0.8	+0.5
18	1	3	1	2	1	0.4	225	0.15	1.3	-0.5
19	2	1	2	1	3	0.8	100	0.25	0.8	+0.5
20	2	2	3	2	1	0.8	150	0.35	1.3	-0.5
21	2	3	1	3	2	0.8	225	0.15	2	0.0
22	2	1	2	2	3	0.8	100	0.25	1.3	+0.5
23	2	2	3	3	1	0.8	150	0.35	2	-0.5
24	2	3	1	1	2	0.8	225	0.15	0.8	0.0
25	2	1	3	2	1	0.8	100	0,35	1.3	-0.5
26	2	2	1	3	2	0.8	150	0.15	2	0.0
27	2	3	2	1	3	0.8	225	0.25	0.8	+0,5
28	2	1	3	2	2	0.8	100	0.35	1.3	0.0
29	2	2	1	3	3	0.8	150	0.15	2	+0.5
30	2	3	2	1	1	0.8	225	0.25	0.8	-0.5
31	2	1	3	3	3	0.8	100	0.35	2	+0.5
32	2	2	1	1	1	0.8	150	0.15	0.8	-0.5
33	2	3	2	2	2	0.8	225	0.25	1.3	0.0
34	2	1	3	1	2	0.8	100	0.35	0.8	0.0
35	2	2	1	2	3	0.8	150	0.15	1.3	+0.5
36	2	3	2	3	1	0.8	225	0.25	2	-0.5

3. RESULTS and DISCUSSION

The test results that obtained for Table 7 were evaluated for surface roughness (Ra), circularity (Cr), and cylindricity (Cy) of the machined parts. Taguchi and ANOVA analyses were performed to determine the effects of cutting tool height and the cutting parameters on the machining geometry of the turned workpieces. Furthermore, 3D graphs were ploted to relate the main influencing factors to the position of the cutting tool relative to the workpiece axis. All evaluations of the results are given below respectively.

For the surface roughness, a portable tester were used. The Ra values that obtained from 0.8 mm cut-off-length method. The measurements were taken from four different surfaces, around of the turned workpiece. Moreover, the deviations for Circularity and cylindricity of the machined parts were performed using a Mahr MMQ 400 model form measuring machine. The controls were performed for two different sections on the machined surface. The average values of the measurements were evaluated for he deviation from Circularity and cylindricity.

3.1. Evaluation of the Surface Roughness (Ra)

Ra values were analyzed by using the Taguchi method. The results are shown in Fig 8 and Table 8. The S/N ratios in Fig 8 clearly show that the main factors affecting Ra are F and Rd. Other factors with less influence on Ra are V, Ap, and H. The ranking values in Table 8 indicate the factors impacting Ra in order of significance. Specifically, the ranking values confirm that F and Rd are crucial test parameters for improving Ra results. Rank 1 signifies that F is the most important factor, while Rank 2 emphasizes that Rd is the second most important factor. In other word, Reducing the feed rate and increasing the insert radius lead to decrease the surface roughness. Also, this mechanism is supported in the literature [32-34]. Furthermore, increasing the cutting speed provide to go down the surface roughness because of that high cutting speeds increase the temperature, reducing the BUE [35]. Conversely, Fig 8 shows that the Ap and H factors are less important on the surface roughness. The H factor is ranked lowest according to the values in Table 8. At first glance, a rank value of 5 might imply that surface roughness is not significantly affected by whether the cutting tool tip is set on or off the workpiece axis. Therefore, ANOVA analysis and 3D graphs are essential for a comprehensive understanding.

ANOVA method was used to obtain the % contribution of the factors for Ra. As a result of the ANOVA, the P value, which determines the probability of independent variable effects, should be taken into account. If the P value is less than 0.05 as a result of the analysis, the result is considered significant [36-37].

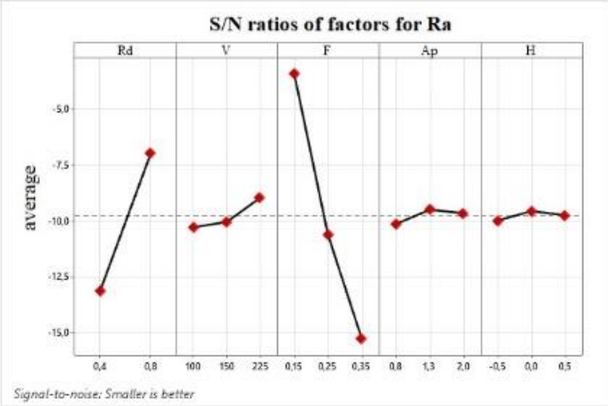


Figure 8. S/N ratios of factors for Ra

Table 8. S/N ratios and effect ordering for Ra

Level	Rd	V	F	Ap	H
1	-13.146	-10.304	-3.421	-10.160	-10.005
2	-6.984	-10.068	-10.641	-9.521	-9.582
3		-8.983	-15.293	-9.674	-9.768
Difference	6.161	1.322	11.872	0.639	0.423
Rank	2	3	1	4	5

When the ANOVA results for surface roughness (Table 9) are examined, it is understood that all factors are statistically significant (P<0.05). The main factors were F (62.51%) and Rd (29.64%). The other factors are respectively as V (2.67%), H (1.37%) and Ap (0.97%). The influence of the H factor is higher than the Ap factor. The coefficient of the reliability for the Table 10 was calculated as 96.18% for R-sq (adj).

Table 9. ANOVA results for Ra

Factor	DF	Seq SS	Factor impact%	Adj SS	Adj MS	F-Value	P-Value
Rd	1	64.294	29.64	64.294	64.2937	271.72	0.000
V	2	5.789	2.67	5.789	2.8945	12.23	0.000
F	2	135.578	62.51	135.578	67.7891	286.49	0.000
Ap	2	2.101	0.97	2.101	1.0507	4.44	0.022
H	2	2.978	1.37	2.978	1.4889	6.29	0.006
Error	26	6.152	2.84	6.152	0.2366		
Total	35	216.892	100.00				

To correlate the H factor with the largest influencing factors are shown in Table 9 and the 3D graphs are given in Fig 9. When Fig 9.a is examined, it is clear that the surface roughness value increases with increasing feed rate. It is also evident that at a feed rate value of 0.35, the value of -0.5 for the H factor is better than other values. Fig 9.b indicates that the largest tip radius and positioning the tool above the center of the workpiece (H: +0.5) improves surface roughness.

When Fig 9.a and 9.b are analyzed together, it can be seen that at a tip radius of 0.4 mm, clamping the cutting tool above the workpiece axis and increasing the feed rate increases the surface roughness value, while the surface roughness value is lower when the cutting tool is clamped below the axis. This is attributed to the wear on the cutting edge, which is weakened due to the increased rake angle, and the uneven distribution of thermal build-up acting on the insert with a small tip radius[3,33].

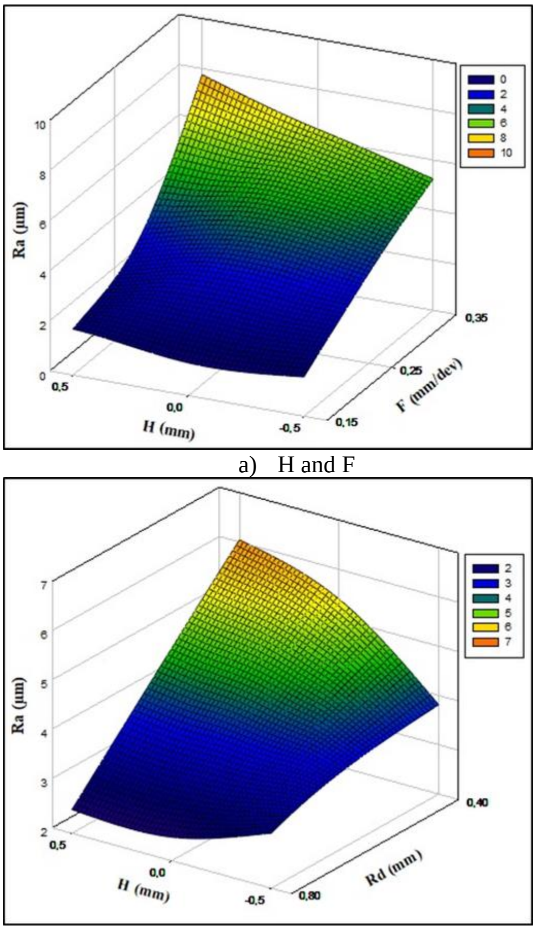


Figure 9. The relationship of the Ra with factors

3.2. Evaluation of Circularity (Cr)

The graph of the S/N ratios for the circularity (Cr) (Fig 10) and the order of influence of the S/N ratios (Table 10) are given below. In table 10, the main factors for the ranks are respectively F, Ap, Rd, H and V. The factor H is fourth in that ordered. At the same time, the table 10 figure out that the height of the cutting tools' tips is more important than the cutting speed. Furthermore, the S/N graph (Fig 10) shows that the cutting tool tip should be udjusted at the axis (H:0.0) or above of the axis (H:+0.5) ability to decrease circularity deviation of the machined surfaces. A decrease in circularity deviation was observed with the cutting tool tip at the work piece axis (H:0.0 mm). However, an increase in circularity deviation was come out the cutting tool tip under the work piece axis (H:-0.5 mm). That results have been attributed to the fact that changing form angles increase the cutting force in the literature [38,39]. By the way, the cutting parameters, such as F, Ap, Rd and V, also taking in to decrease the circularity deviation. It is pointed by the Fig 10 that the circularity deviation can be gone down if the cutting parameters are used in the optimal values. For example, the 0.15 is a minimum value for F factor to reduce the circularity deviation. It is clearly understood that the values of the circularity deviation increase with rising of the feed rate. Also, the lowest value (0.8 mm) for the depth of cut, Ap factor, improve the circularity machined surface. The largest value (0.8 mm) for radius of the cutting tool tip, Rd factor, provide to decrease the circularity deviation. The highest value (225 m/min) for the last parameters, V factor, needs to implemented the circularity of the machined surface.

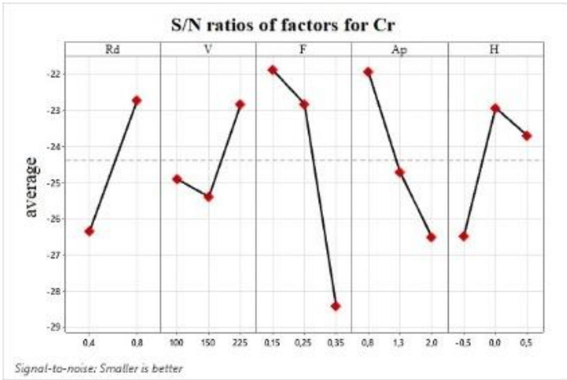


Figure 10. S/N ratios of factors for Cr

Table 10. S/N ratios and order of influence for circularity (Cr)

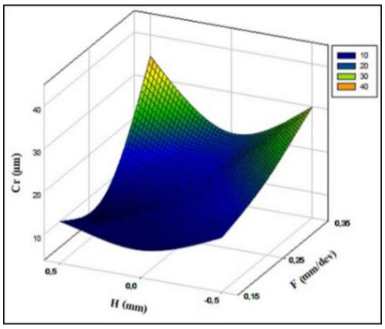
Level	Rd	V	F	Ap	H
1	-26.36	-24.91	-21.89	-21.93	-26.50
2	-22.74	-25.39	-22.83	-24.71	-22.94
3		-22.85	-28.43	-26.51	-23.71
Difference	3.62	2.55	6.53	4.58	3.55
Rank	3	5	1	2	4

When the ANOVA results (Table 11) were examined that all factors were statistically significant ($P<0.05$), except for the V factor. The factor with the greatest impact was F (amount of progress). This was followed by Ap (19.65%), Rd (12.36%) and H (10.89%), respectively. The results showed that the cutting tool height adjustment was effective for the circularity deviation. The coefficient of the reliability for this ANOVA model was estimated as 88.27% for R-sq(adj).

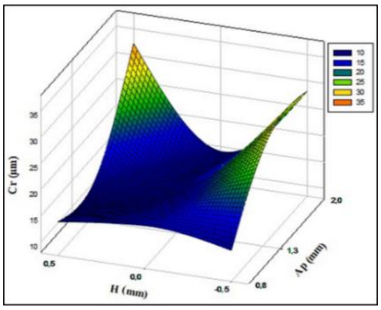
Table 11. ANOVA results for Cr

Factor	DF	Seq SS	Factor Impact%	Adj SS	Adj MS	F-Value	P-Value
Rd	1	400.00	12.36	400.00	400.000	36.86	0.000
V	2	7.39	0.23	7.39	3.694	0.34	0.715
F	2	1559.06	48.16	1559.06	779.528	71.83	0.000
Ap	2	636.22	19.65	636.22	318.111	29.31	0.000
H	2	352.39	10.89	352.39	176.194	16.24	0.000
Error	26	282.17	8.72	282.17	10.853		
Total	35	3237.22	100.00				

Additionally, 3D graphs, shown in Fig 11, were plotted to reveal the relationship between the H factor and the most effective parameters that are shown in Table 11. When Fig 11.a is examined that the circularity error goes up with the rise of the feed rate. Generally, it is said that 0.0 value of the H factor is better than the other values for Cr. Other hand, the effect of cutting tool height adjustment at the low feed rates (0.15 mm/rev, 0.25 mm/rev) on the circularity is smaller than at high feed rate (0.35 mm/rev). Fig 11.b, At the lover cutting depth for all tool position, the circularity deviation was decreased. When Ap goes up, the circularity deviation also raised for all levels of the H factor.



a) H and F



b) H and Ap

Figure 11. The relationship of Cr with factors.

3.3. Evaluation of Cylindricity (Cy)

The results of the cylindrical deviation (Cy) are evaluated by Taguchi method. The graph of the S/N ratios for Cy is illustrated at Fig 12 and the order of the effects of the cutting factors were shown in Table 12 below. The Fig 12 presents the influences of the test parameters on the Cy results. Generally, it is seen that all test parameters affect the cylindrical deviation. That is evidenced by the Rank values of the Table 12. The main factors are F, Ap, Rd, H and V respectively. In this ranking, the H factor is in the 4th place. Considering the H factor, a decrease in the cylindrical deviation was observed with the of the cutting tool at the work piece axis (H: 0 mm). Moreover, the cylindrical deviation increased when the cutting tool was below (H:-0.5 mm) from the work piece axis. The rise of deviation is attributed to the fact that changing form angles increase the shear force [38,39]. By the way, the biggest change is seen in the F factor. It is known that the cylindrical deviation diminished by lower the feed rate. Likewise, to reduce the Ap values improved the Cy values. When the Rd factor was examined, it was determined that the increase in the tip radius lead to go down the Cy values. The effect of the cutting speed on the cylindrical deviation was the least in the V (cutting speed) factor.

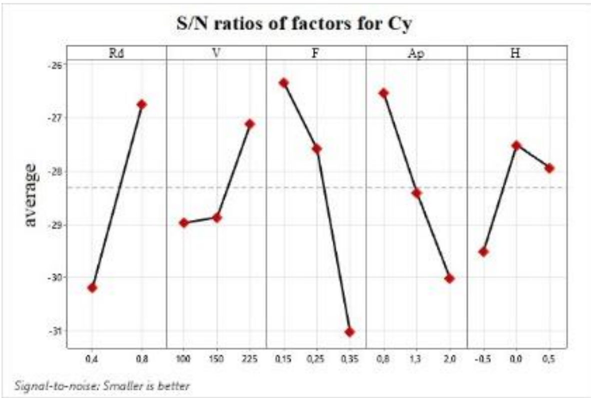


Figure 12 S/N ratios of factors for Cy.

Table 12. S/N ratios effect rank for Cy

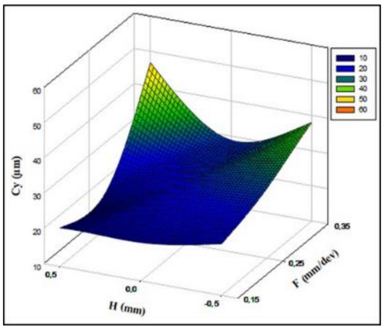
Level	Rd	V	F	Ap	H
1	-30.20	-28.97	-26.34	-26.53	-29.51
2	-26.75	-28.87	-27.58	-28.41	-27.51
3		-27.11	-31.04	-30.02	-27.94
Difference	3.45	1.86	4.70	3.49	2.00
Rank	3	5	1	2	4

When the ANOVA results (Table 13) for Cy were analysed, all factors were considered to be statistically significant ($P<0.05$), except for the V factor. The factor with the greatest impact was F (41.85%). This was followed by Rd (23.90%), Ap (20.54%) and H (4.49%). The ANOVA results show that the cutting tool height adjustment affects the cylindrically as %4.49. The coefficient of reliability for this ANOVA model was evaluated to be R-sq(adj): 88.65%.

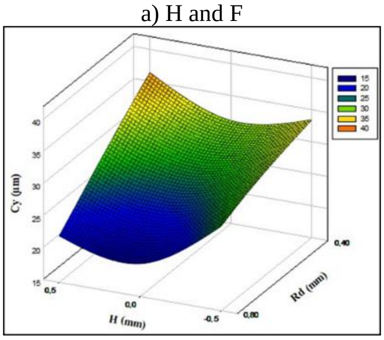
Table 13. ANOVA results for Cy.

Factor	DF	Seq SS	Factor Impact%	Adj SS	Adj MS	F-Value	P-Value
Rd	1	920.11	23.90	920.11	920.111	73.71	0.000
V	2	30.89	0.80	30.89	15.444	1.24	0.307
F	2	1611.56	41.85	1611.56	805.778	64.55	0.000
Ap	2	790.72	20.54	790.72	395.361	31.67	0.000
H	2	172.72	4.49	172.72	86.361	6.92	0.004
Error	26	324.56	8.43	324.56	12.483		
Total	35	3850.56	100.00				

Furthermore, some 3D graphs, given in Fig 13, were plotted to investigate the relation of the H factor with the largest impact factors. Normally, Fig 13.a is examined that the cylindrical errors go up with the rising of the feed rate. Generally, it is understood that the H factor value is 0.0 provide to improve the cylindrical tolerance for all values of the feed rate. But, it could be say that the cutting tool under the work piece axis (H:-0.5 mm) is better than the cutting tool upper the work piece axis (H:+0.5 mm). For example, the cylindrical error is lower when the cutting tool was at the level -0.5 and at the high feed rate (0.35 mm/rev). A similar situation can be seen in the Fig 13.b graph. However, it is seen that the +0.5 value of the H factor is better than the -0.5 value by using the larger tip radius (0.8 mm) of the cutting tool.



a) H and F



b) H and Rd

Figure 13. The relationship of Cy with the main factors.

Lastly, two samples for removable chips were given in Fig 14. Generally, it can be said that each forms of the chips are nearly similar. But, it seems that the chip, shown Fig 14.b, was deformed more than the other chip, illustrated in Fig 14.a. It is thought that the normal rake angle on the negative cutting tool was enlarged when tool tip is under (-0.5 mm) the axis of the workpiece (a° values for -0.5 level are bigger than other levels in Table 4).

a) H: -0.5 mm b) H: 0.0 mm

Figure 14. Removal chips obtained with Rd: 0.4, V: 100 m/min, F: 0.25 mm/rev, Ap: 2 mm,

4. CONCLUSION

In this study, an experimental work was performed to clarify the effects of the variable heights of the cutting tool tip and the cutting parameters on the geometry of the turned AISI 304 stainless steel. The test results were evaluated with Taguchi and ANOVA analysis to relate with the geometric features, for example, surface roughness, circularity and cylindricity.

(1) To improve surface roughness when turning AISI 304 material, the height of the cutting tools must be considered. Adjusting the cutting tool to the workpiece axis (H: 0.0 mm) is not sufficient to reduce surface roughness. The contribution of height adjustment to surface roughness was determined to be 1.37% by ANOVA analysis. The 3D graphs indicated that the effect on surface roughness should not be overlooked. Placing the cutting tool above the workpiece axis (H: +0.5 mm) with inserts having a small radius (0.4 mm) resulted in higher surface roughness at higher feed rates. This is attributed to the wear on the cutting edge, which is weakened due to the increased rake angle[3,33,38,39].

(2) The feed rate was determined the most effective factor on the surface roughness. The amount of contribution of the feed rate for surface roughness was found out as 62.51%. Then, the insert radius was detected the second main effective factor. To large the cutting edge radius lead to reduce the surface roughness value. The contribution of the tip radius on the surface roughness was calculated nearly 29.64%. Rising the cutting speed induced to go the surface roughness value down. The effect of cutting speed was defined as 2.67%. Eventually, the effect of the depth of cut was appeared to be very low value, as 0.97%.

(3) The effect of the height of the cutting tool on the circularity tolerances (Cr) is nearly as 10.89%. It is determined that the cutting tools should be adjusted at the centre of the parts (H:0.0) to improve the circularity of the machined surface. But, it is

evaluated that the depth of cut and the height is together, at the lower value, H:+0.5 and H:-0.5 belter than H:0.0. Moreover, it can be said that the H:+0.5 value for the cutting tool is relatively better than the H:-0.5 value to get the low circular deviation. The most effective factor for the circularity was detected the feed rate. The percentage of the effect for the feed rate was as 48.16%. It was determined that the circularity deviation increased with the increase of the depth of cut. The effect of the cut depth was 19.65%. Moreover, the insert radius was an important factor in the reduction of the circular deviation. The effect for radius was found 12.36%.

(4) For cylindricity, the contribution of cutting tool height was evaluated as 4.49%. The 3D graphs show that H:+0.5 is better than H:-0.5 except for the highest feed rate (0.35 mm/rev) and the highest depth of cut (2 mm). Additionally, the most influential factors on cylindricity and circularity were feed rate and tip radius of the insert. The value of cylindrical deviation increased with increasing feed rate and decreasing tip radius. It was shown that the effect of feed rate was 41.85% and the effect of tip radius was 23.90%. The higher the depth of cut, the higher the cylindrical deviation value, contributing 20.54%.

Finaly, it is recommended the researcher who will study about this subject, they should investigate the relation of the tool height with the diameter of the machined parts.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Yunus KAYIR: The manuscript was written and edited.

Ercan DEMİRER: The tests were carried out.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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