[Mansoura Engineering Journal](https://mej.researchcommons.org/journal)

Volume 49 | Issue 5 Article 10

2024

Investigating the Impact of Cutting Parameters on Roundness and Circular Runout Using Signal-to-Noise Ratio Analysis

Enas Abdel-Fattah Taha
Production and Mechanical Design Engineering Dept., Faculty of Engineering, Mansoura University, 35516 Mansoura, Egypt

Mona. A. AbouEleaz
Production and Mechanical Design Engineering Dept., Faculty of Engineering, Mansoura University, 35516 Mansoura, Egypt

Ossama Badie Abouelatta
Production and Mechanical Design Engineering Dept., Faculty of Engineering, Mansoura University, 35516 Mansoura, Egypt, abouelatta@mans.edu.eg

Fatma Abdallah Elerian
Department of Mechanical Engineering, College of Engineering, University of Bisha, P.O. Box 001, Bisha 67714, Saudi Arabia, on leave from Production and Mechanical Design Engineering Dept., Faculty of Engineering, Mansoura University, 35516 Mansoura, Egypt

ORIGINAL STUDY

Investigating the Impact of Cutting Parameters on Roundness and Circular Runout Using Signal-to-noise Ratio Analysis

Enas A.-F. Taha [a], Mona A. AbouEleaz [a], Ossama B. Abouelatta [a,*], Fatma A. Elerian [a,b]

[a] Department of Production and Mechanical Design Engineering, Faculty of Engineering, Mansoura University, Mansoura, Egypt
[b] Department of Mechanical Engineering, College of Engineering, University of Bisha, Bisha, Saudi Arabia

Abstract

Geometric dimensioning and tolerancing (GD and T) principles are crucial for achieving accuracy in machining. It is important to try to avoid possible errors when manufacturing the product, such as errors resulting from the machining process. In this paper, the effect of some cutting factors will be studied during the machining parameters (feed, speed, and depth of cut) on free-cutting steel samples that are widely used in the industry by exploring their effects on the roundness, and circular runout errors. The experiments were designed using the standard fractional factorial design L27 orthogonal array Taguchi method. Statistical methods are applied to find which machining parameters are appropriate, and the best values to obtain the least possible errors during the operation process. Results are analyzed using the average signal-to-noise ratio, the smaller the values, the better the roundness and circular runout. Higher cutting speed improves roundness while increasing feed worsens roundness and improves runout.

Keywords: Cutting parameters, Roundness, Runout, Signal-to-noise ratio

1. Introduction

Manufacturing requires assembly parts to meet dimensional and geometric specifications, influenced by factors like tool geometry, material selection, machining speed, feed, and depth of cut to minimize errors and maintain product quality. Optimizing tool geometry and material selection is crucial for precise manufacturing outcomes, as tool geometry impacts machining performance, wear resistance, tool life, and part accuracy (Liao et al., 2024). Therefore, understanding influencing factors and focusing on precise tool geometry and material selection can minimize errors in manufacturing, requiring further research to enhance precision (Gao et al., 2019). These principles define variables like roundness, concentricity, and runout (Ameta et al., 2015; Meadows, 2009). Roundness is an ideal geometric shape, while runout measures deviation from the ideal shape relative to an axis, assessing the quality of rotating components, engines, and gearboxes (Elerian et al., 2021; Némedi et al., 2017; Saglam et al., 2005). Others compare roundness error estimation methods using a calibrated instrument and different filtering techniques, finding the minimum zone circle filtering method provides the lowest error values (Elerian et al., 2021).

Parameters affecting roundness during machining in precision manufacturing are analyzed to focus on the primary goal of achieving optimal cylindrical component functionality and quality. Cutting speed significantly influences roundness characteristics in materials like cylindrical steel bars. The interplay between speed, feed rate, and depth of cut is crucial for achieving desired results (Rico et al., 2010). It is evident that each parameter cutting speed, feed rate, depth of cut, and cooling method plays a significant

Received 18 April 2024; revised 29 June 2024; accepted 6 July 2024.
Available online 13 August 2024

* Corresponding author at: Department of Production and Mechanical Design Engineering, Faculty of Engineering, Mansoura University, 35516, Mansoura, Egypt.
E-mail address: abouelatta@mans.edu.eg (O.B. Abouelatta).

https://doi.org/10.58491/2735-4202.3235

role in determining the roundness and overall quality of cylindrical components. For instance, optimizing cutting speed and feed rate can directly improve the surface finish and dimensional accuracy of machined parts, thereby enhancing their functionality and longevity (Saglam et al., 2005). The cooling method is critical for SUS 303 stainless steel, affecting roundness and surface roughness (Jirapattarasilp and Kuptanawin, 2012). Employing advanced cooling methods and optimization algorithms can further refine these outcomes, particularly for complex materials and geometries (Islam et al., 2013). Cutting speed affects the hard turning of the inner ring bore, surface roughness, and inner diameter error (Boy et al., 2015). The Taguchi method is effective in studying the improvement of surface roughness and roundness in aluminum alloys (Soenoko et al., 2017). Advanced techniques like Duelist and genetic algorithms optimize roundness and reduce errors (Elsadek et al., 2020).

Researchers have used techniques like the Taguchi method, analysis of variance, and signal-to-noise ratio (S/N ratio) to study roundness in materials like gray cast iron brake drums (Manivasagam and Richard, 2023; Rafai and Islam, 2009). A study focused on EN25 steel emphasizes the importance of cutting parameters like higher speeds and lower feeds for minimizing errors and optimizing dimensional accuracy (Singaravel et al., 2016). The Taguchi method is expected to aid in investigating precision machining practices (Chou et al., 2005). A study uses optimization techniques like TOPSIS and Taguchi to optimize cutting speed, feed rate, and depth of cut in turning EN25 steel (Balasubramaniyan and Selvaraj, 2017). Another examines materials like AISI 1045, Inconel 718 (Mishra et al., 2013; Tzou et al., 2006), UNS A97075-T6, alloy tool steel SKD 11, and steel 4140 (Martín-Béjar et al., 2019; Rafai and Islam, 2011; Tzeng and Yang, 2008), revealing the complex relationship between these factors and roundness. The impact of filters on roundness error values, specifically 2CR50, 2CR75, and Gaussian filters, was examined (Elerian, 2022). It becomes clear that the selection of machining parameters significantly impacts the roundness and overall quality of the components. For instance, the Taguchi method, with its robust design and analysis capabilities, can effectively optimize machining parameters to achieve desired quality in diverse materials. Techniques like TOPSIS further aid in making multi-criteria decisions, enhancing the precision of machining processes.

The impact of parameters on runout in machining processes is focused on the development of a force model for metal processing in ball milling (Feng and Menq, 1994). A model predicts cutting forces and analyzes milling cutter concentricity, particularly important for machining curved surfaces (Zheng et al., 1999). A method has been developed to determine coefficients in ball milling, using a single cutting force measurement to evaluate runout position angle and offset, improving precision machining (Ko and Cho, 2005). An innovative method for face milling calibrates tool runout error and cutting force coefficient, and a method for predicting slow roll runout is introduced (Wan et al., 2007b). These studies highlight the significant progress made in understanding and mitigating runout effects in machining processes. The models and calibration techniques developed provide a comprehensive approach to enhance machining accuracy. Specifically, the methods for determining cutting force coefficients and runout angles are crucial for achieving precision in milling operations (Chen et al., 2022).

A new method for calculating cutting forces during precision milling has been introduced, confirming the validity of predictive model results (Wan et al., 2007a). A method minimizes out of roundness effects on cutting forces in micromachining (Bissacco et al., 2008). A new calibration method is introduced, using three models to account for high values and improve accuracy (Wan et al., 2009). Algorithms in milling, aided by static dynamometer measurements, aim to predict cutting parameters with near-error-free accuracy, enhancing precision (Rivière-Lorphèvre and Filippi, 2009). A study discussed the impact of factors like titanium alloy surface milling machines, tool runout parameters, and cutting force on accuracy (Wan et al., 2011). A two-level monitoring system detects runout errors in Ti6Al4V and W78Cu22 alloys (Beruvides et al., 2014). Advancements in precision milling include innovative methods and calibration techniques, improve cutting force predictions and runout errors. The use of multiple models and advanced computational tools is a trend (Abeni et al., 2024).

A micro-milling force model is proposed for micro-milling, analyzing tool deflection, spindle runout, and chip thickness to determine undeformed chip thickness and maximum allowable cutting force (Wang et al., 2012). A model is developed to investigate the effects of tool runout, tool motion, path, and tool type on cutting forces, improving computational accuracy (Zhang et al., 2016). A new method for calibrating circular runout parameters of milling cutters is introduced, highlighting the importance of careful calibration (Li et al., 2020). The micro-milling force model, focusing on tool deflection, spindle runout, and chip thickness, offers a comprehensive framework for optimizing micro-milling operations. It determines undeformed chip thickness and maximum cutting force, enhancing precision and efficiency. It also addresses computational accuracy factors. The method for calibrating circular runout parameters underscores the necessity of meticulous calibration in milling operations. By emphasizing the importance of calibration, this method ensures that milling cutters operate with minimal runout, thereby improving the overall accuracy and quality of the machining process (Yang et al., 2023).

The study explores the impact of cutting parameters on turning operations, highlighting the need for optimal roundness and circular runout in mechanical parts. It suggests optimal cutting speed, feed, and depth of cut to reduce dimensional errors and enhance part quality, underscoring potential advancements in precision manufacturing and machining operations.

2. Material and methods

2.1. Material

A round bar made of ST37 steel has been selected with a hardness of 30 HRC. ST37 steel has a low carbon content of less than or equal to 0.36% and is known for its mechanical properties such as low hardness, high ductility, and easy formability. These special properties make ST37 steel the material of choice for a wide range of applications. ST37 steel is a versatile material used in structural engineering, construction, automotive, machinery parts, pressure vessels, and general fabrication tasks due to its strength, weldability, and excellent formability, making it a preferred choice in various industries. The mechanical and physical properties of ST37 alloy steel are shown in Table 1 and represent a well-balanced material that combines good ductility with high tensile and yield strengths, making it suitable for various applications. The physical properties provide a comprehensive overview of the material's properties.

When evaluating the chemical composition of ST37 steel, it becomes clear that it is a low to medium-carbon steel with low levels of alloying elements such as manganese and silicon, Table 2.

Table 2. Chemical composition (wt%) of ST 37 alloy steel.

Iron, Fe	Carbon, C	Manganese, Mn	Phosphorus, P	Silicon, Si
98	0.36	0.9	0.04%	0.15–0.40%

These elements work together to provide a balance of strength, ductility, and toughness. The low phosphorus and sulfur content is positive, as it helps maintain good machinability and prevents brittleness. Overall, the composition is well suited for a wide range of applications, from structural components to manufacturing machinery, where a combination of strength and processability is required. Engineers and manufacturers can use this chemical composition data to make informed decisions about the use and processing of ST37 steel in various industrial applications.

2.2. Sample preparation and machining condition

In the experimental setup, cylindrical steel rods measuring 40 mm in diameter and 80 mm in length are used. Iterative turning operations were carried out on each sample to achieve the final shape depicted in Fig. 1. The workpieces were firmly clamped and held in place using a three-jaw chuck, a widely used and reliable workpiece holding device commonly used in machining operations. Choosing a 3-jaw chuck can go a long way in ensuring that the workpiece remains stable and securely held during machining, reducing the chances of vibration, misalignment, or workpiece shifting.

The specimens were machined using a CNC lathe, specifically a Victor Vturn Plus 20-2011 model equipped with FANUC's control model (0i-TD). It has 260 mm turning diameter, and 400 mm turning length, as shown in Fig. 2. The CNC lathe offers versatile X-axis travel options, critical for machining efficiency. This model provides a positioning accuracy of ±0.005 mm and a repeatability of ±0.003 mm. Carbide inserts, typically made from tungsten carbide, are used in turning and finishing operations on materials like steel, stainless steel, cast iron, and non-ferrous metals. The recommended machining conditions include a cutting speed of 150–400 m/min, feed of 0.05–0.25 mm/rev, and depth of cut of 0.5–3.0 mm. The MV chip breaker is designed for medium finishing operations, providing effective

Table 1. Mechanical and physical properties of alloy steel ST37.

Mechanical properties					Physical properties			
Elongation	Tensile Strength, Ultimate	Tensile Strength, Yield	Shear Modulus	Hardness Brinell	Density	Melting Point	Thermal Conductivity	Electrical Conductivity
25%	415 MPa	205 MPa	80.0 GPa	149	7.80 g/cm^3	1420–1460 °C	53 W/MK	6.9% IACS

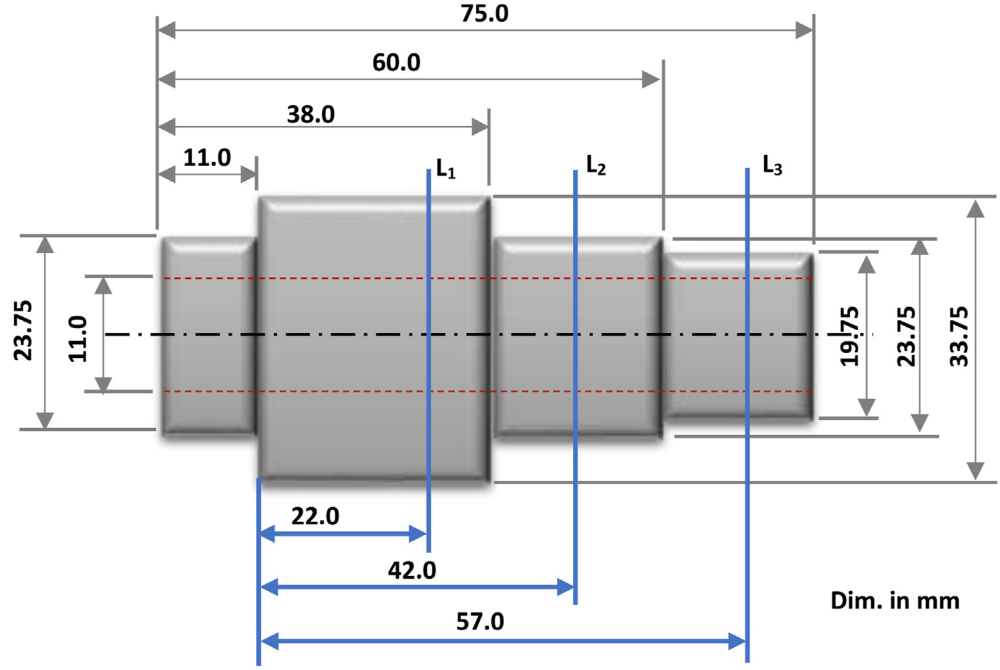


Fig. 1. The dimension of the experimental workpieces.

Fig. 2. CNC lathe machine (Victor Vturn Plus 20-2011 model).

control over chip formation, smooth machining, and preventing chip clogging. Ball screw diameter and lead specifications ensure precision and quality in specific tasks.

Table 3 details CNC lathe spindle characteristics, including spindle speed, motor power, bore, and tie rod specifications. These details help engineers select appropriate settings and tool options for specific machining needs, and ensure compatibility with different workholding and tooling solutions.

An SVJBL-2020-K16 left external turning tool holder, with a 125 mm length, 93° clearance angle, and 16 mm cutting edge, is used in the experiments. It is commonly used for machining high-temperature alloys and high-tensile steels due to its cost-effectiveness. Carbide inserts type DCMT070204-MV are used as cutting tools to perform machining operations. Known for their exceptional hardness and durability, carbide inserts are ideal for a range of machining tasks, from turning to milling. Carbide inserts are effective for precise cuts, maintaining edge integrity over time. They have precision cutting edge, reducing material buildup, extending tool life, and offering cost-effectiveness, making them the superior choice for fine finish.

The sample preparation process involves mounting the specimens on a CNC lathe, turning each sample to the required design, machining, and performing a systematic process. This includes rough turning, and finish turning, applying different depths of cut to each sample. The cutting process was conducted using existing machines in the workshop, ensuring controlled conditions and increased reliability and reproducibility of results.

Table 3. Specifications of CNC turning machine: spindle characteristics, speed, power, and bore.

Spindle nose (chuck)	Max. spindle speed	Spindle motor power	Bearing inside diameter	Spindle bore	Hole through the drawbar
A2–6 (8′)	4200 rpm	7.5/9.0 KW	100 mm	62 mm	52 mm

2.3. Measurements of roundness and circular runout

Roundness and circular runout measurements are crucial for evaluating the precision of cylindrical parts, as they measure deviation from a perfect circle and surface profile variation during rotation. Roundness and circular runout are conducted using RA-120 roundness measuring device. The RA-120 measuring system, manufactured by Mitutoyo, is used for accurately measuring roundness and run-out, offering high-precision measurements in a narrow range of ±1000 μm or less, Fig. 3.

This study prepared 27 samples for measurement experiments, dividing them into three cross-sectional areas for roundness measurement and runout. Preparing measurement equipment and accessories is crucial for precise and reliable results. Proper configuration and customization are essential to minimize errors and maintain measurement integrity throughout the testing process, as potential errors can affect results validity.

Fig. 3. The main units of RA-120 measuring system.

All measurements were performed according to the procedures outlined in the RA-120 user manual. The centering key ensures accurate measurements, reduces errors, and increases data reliability. The measurements are based on a Gaussian filter, least square circle calculation method, 2000x display magnification, and a cutoff value of 50 undulations per revolution.

Once the roundness measurement screen can be accessed, carefully position the stylus at the intended measurement location on the workpiece, as shown in Fig. 4a. This positioning of the probe is critical to starting the roundness measurement process and ensuring accurate data collection from the workpiece. Results are displayed, and users can print or save data for later analysis. Runout measurements follow roundness measuring steps, but differ by critical choice of analysis items, Fig. 4b. The probe position is customized to meet the specific requirements of each measurement type, ensuring precise data collection for roundness and runout evaluation. Fig. 5 shows a roundness measurement of a sample.

2.4. Design of experiments

This study utilized Taguchi's design of experiments method, a standardized and structured approach, to plan its experimental design. This method ensures minimal experiments, minimizes resource requirements, and maximizes efficiency while producing meaningful results. The cutting parameters (cut speed, feed, and depth of cut) were carefully selected based on the machine's operational capabilities and cutting conditions, with three different levels assigned. Table 4 presents data on

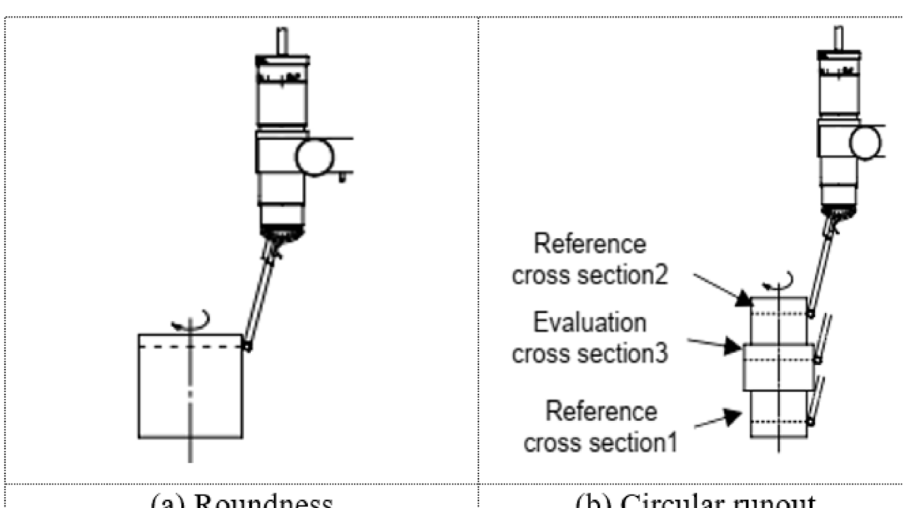


Fig. 4. Setting the stylus measurement.

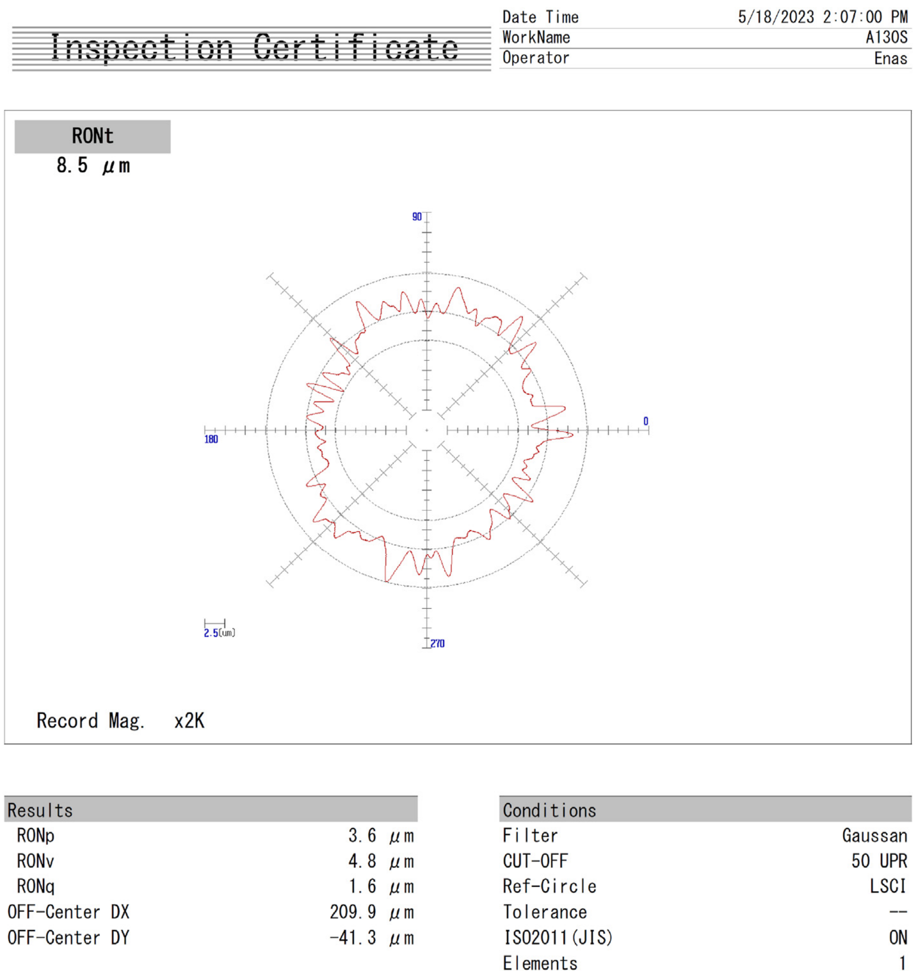


Fig. 5. Roundness measurement of a sample.

Table 4. Process cutting parameters and their levels.

Factors	Levels		
	Level (1)	Level (2)	Level (3)
Cutting speed (m/min)	80	110	140
Feed (mm/rev)	0.10	0.15	0.20
Depth of cut (mm)	0.50	1.00	1.50
Level of measurement (mm)	22.0	42.0	57.0

cutting parameters, including cutting speed, feed, and depth of cut, in the experimental study. In addition, it shows the three level of roundness and circular runout measurements (L1, L2 and L3), as shown in Fig. 1.

Table 5 displays the Taguchi L27 testing number combinations of parameters table, consisting of 27 rows and three columns, and outlines the specific combinations of cutting parameters used in the experimental study. The table outlines a systematic plan for experiments, examining factors like cutting speed, feed, depth of cut, and their impact on machining outcomes, including out-of-roundness, and circular runout. The table provides a clear roadmap for conducting experiments, enhancing scientific rigor and reliability, and aiding in data collection and analysis for process optimization.

3. Results and discussions

The roundness error and the circular runout achieved during the turning of samples were measured after the experiments performed according to the L27 orthogonal array. The lowest values of the out-of-roundness and the runout significantly improve the quality of the product. The present investigation used analysis of variance and lower-the-better S/N ratios to determine the ideal cutting parameters that may impact circular runout and out-of-roundness.

3.1. Effect of cutting parameters and workpiece diameter

The impact of cutting parameters on roundness is demonstrated in Fig. 6a, comparing three cutting

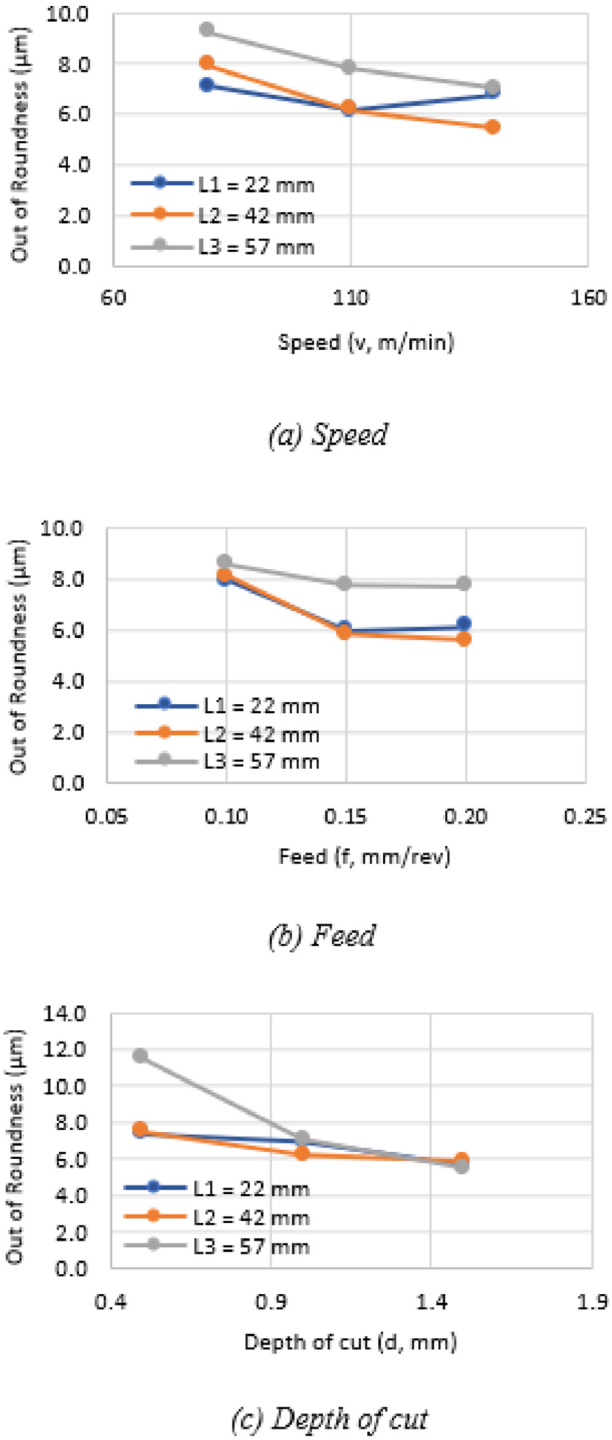
Table 5. Experimental average roundness and circular runout results.

Number	Speed (v, m/min)	Feed (f, mm/rev)	Depth of cut (d, mm)	Average out-of-roundness (μm)	Average circular runout (μm)
1	80	0.10	0.5	11.39	24.82
2	80	0.10	1.0	9.33	16.50
3	80	0.10	1.5	6.40	10.83
4	80	0.15	0.5	10.94	15.81
5	80	0.15	1.0	8.77	15.70
6	80	0.15	1.5	5.00	17.23
7	80	0.20	0.5	8.78	15.21
8	80	0.20	1.0	7.17	23.23
9	80	0.20	1.5	5.26	22.40
10	110	0.10	0.5	10.18	16.97
11	110	0.10	1.0	8.10	11.43
12	110	0.10	1.5	5.67	7.45
13	110	0.15	0.5	8.53	22.53
14	110	0.15	1.0	5.40	10.00
15	110	0.15	1.5	4.00	14.37
16	110	0.20	0.5	7.03	17.43
17	110	0.20	1.0	5.63	20.70
18	110	0.20	1.5	5.77	24.77
19	140	0.10	0.5	8.20	20.90
20	140	0.10	1.0	5.97	15.93
21	140	0.10	1.5	8.73	17.33
22	140	0.15	0.5	6.30	8.17
23	140	0.15	1.0	5.13	8.77
24	140	0.15	1.5	4.77	9.67
25	140	0.20	0.5	7.97	14.10
26	140	0.20	1.0	5.03	12.13
27	140	0.20	1.5	5.70	20.17

speed levels (80, 110, 140 m/min) with out-of-roundness in μm. The overall impact of cutting speed on the three levels of measurements suggests that the most favorable out-of-roundness values are generally observed at a cutting speed of 140 m/min, but particularly at a level of 42 mm (L_2). The free end part of the specimen, characterized by the smallest diameter and thickness, exhibited the highest out-of-roundness values at level $L_3 = 57$ mm for the various speeds. Fig. 6b demonstrates the correlation between the feeds (0.10, 0.15, 0.20 mm/rev) and the out-of-roundness. The minimum out-of-roundness value is observed at $L_2 = 42$ mm for various feeds, with the most favorable result obtained at f = 0.2 mm/rev. Conversely, the maximum out-of-roundness values is observed at $L_3 = 57$ mm. The roundness is influenced by the depth of cut (d), and the most optimal values are observed at d = 1.5 mm, as shown in Fig. 6c. Overall, the measurements suggest that the most favorable outcomes are typically achieved when the depth of cut is set at $L_2 = 42$ mm. The out-of-roundness values at a depth of cut of 1.5 mm are nearly identical. However, the optimal out of roundness value is obtained at a length of $L_3 = 57$ mm and a depth of cut of 1.5 mm.

Fig. 7a shows the impact of cutting parameters on circular runout, comparing the three cutting speed levels with circular runout in μm. Based on the analysis of cutting speed, it can be concluded that the optimal circular runout values are often achieved at a speed of 140 m/min. However, a more specific value of 42 mm, labeled as L_2, is particularly effective. The correlation between the feed and circular runout is shown in Fig. 7b. The minimum circular runout values are observed at $L_2 = 42$ mm and f = 0.15 rev/min. The depth of cut shows that there are no significant differences between the depth of cut and circular runout. This suggests that the variations observed in these measurements can be attributed to random chance or noise rather than any systematic differences between variables, Fig. 7c.

Fig. 8 displays the contour plot illustrating the relationship between roundness and circular runout concerning speed and feed. The y-axis corresponds to the cutting speed, measured in meters per minute, while the x-axis corresponds to the feed, measured in millimeters per revolution. The plot's color gradients represent varying degrees of roundness and circular runout. The color blue is most likely associated with lower roundness values, whereas the color green is indicative of higher roundness values. The objective of this plot is to visually represent the influence of different cutting speeds and feed on the roundness and circular runout of a workpiece. These charts aid in the selection of the most efficient cutting parameters

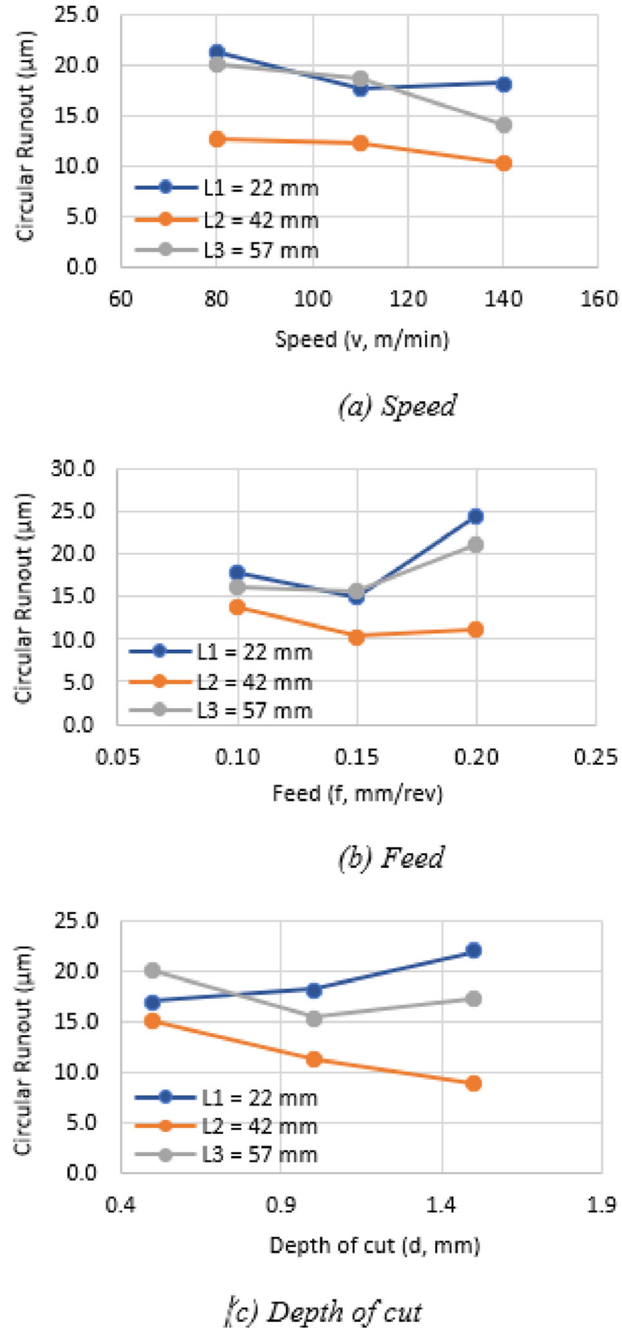


(a) Speed

(b) Feed

(c) Depth of cut

Fig. 6. Interaction plots for out-of-roundness.



(a) Speed

(b) Feed

(c) Depth of cut

Fig. 7. Interaction plots for circular runout.

(speed and feed) that reduce both out-of-roundness and circular runout.

3.2. Effect of cutting parameters on roundness

The interaction plots for the out-of-roundness using Mintab Software are given in Fig. 9. As the cutting speed increases from 80 to 140 m/min, the average out-of-roundness improved from 8.12 to 6.42 μm, which indicates that higher speeds lead to better roundness. This is often seen in machining processes where higher speeds can result in smoother finishes. Increasing the cutting speed has a positive impact on surface roughness, resulting in improved roundness and circular runout (Çiçek et al., 2012). When the feed (f) increases from 0.10 to 0.20 mm/rev, the average out-of-roundness

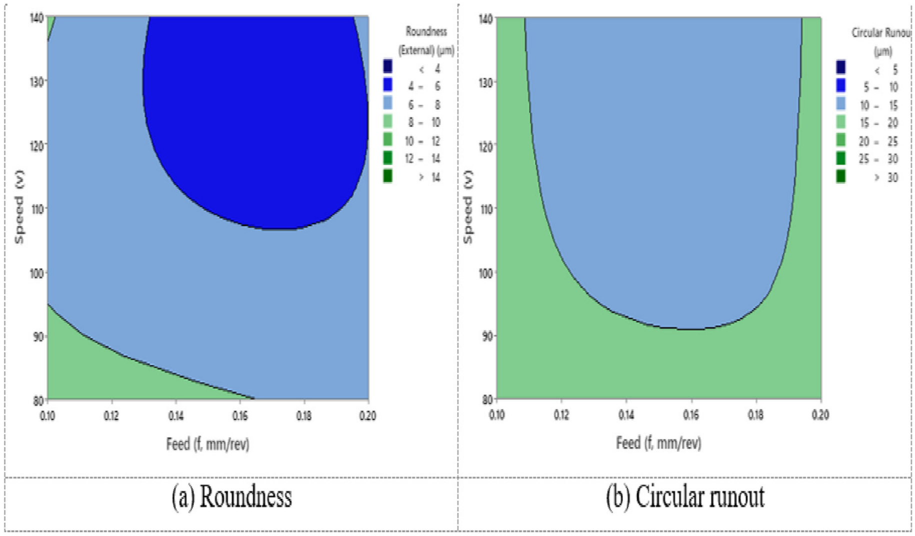


Fig. 8. Contour plot of roundness and circular runout versus speed, and feed.

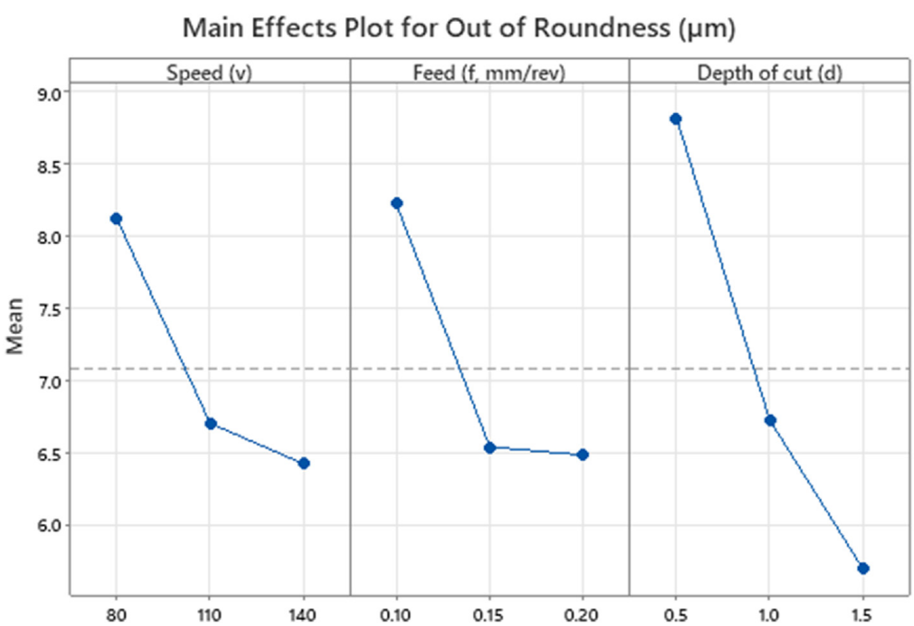


Fig. 9. Main effects plots for the out-of-roundness.

decreases from 8.22 to 6.48 μm. This suggests that higher feed results in slightly better out-of-roundness. The out-of-roundness decreases from 8.81 to 5.70 μm as the depth of cut (d) increases from 0.5 to 1.5 mm. The out-of-roundness and circular runout may vary depending on the depth of cut, occasionally decreasing or increasing. This depends on whether the cutting operation is performed using the tool's nose radius or the cutting edge of the tool (Scippa et al., 2013).

3.3. Effect of cutting parameters on circular runout

Similar to out-of-roundness measurements, higher cutting speeds generally lead to reduced circular runout. This is advantageous because a lower circular runout indicates better concentricity of the machined part. Faster cutting speeds can result in reduced vibration and tool deflection, contributing to improved circular runout (Abouelatta and Madl, 2001). The impact of feed on circular runout is noticeable, especially when comparing the lowest and highest feeds. Higher feeds contribute to better circular runout, which means that the tool follows a more precise path during machining (Şeker et al., 2004). The depth of cut doesn't exhibit a clear trend with circular runout in this dataset. The depth of cut has a similar trend to the feeds when considering circular runout in this dataset.

Fig. 10 shows the interaction plots of cutting parameters on circular runout. For circular runout, as the cutting speed (v) increases, the average runout decreases. This means that higher cutting speeds result in better circular runout, with the average decreasing from 17.97 to 14.13 μm. Similar to the measurements of out-of-roundness, an increase in feed (f) also leads to a decrease in circular runout. The average circular runout reduces as the feed and depth of cut increase from 0.10 to 0.15 mm/rev and 0.5–1 mm, respectively. The feed decreased from 15.80 to 13.58 μm, while the depth of cut decreased from 17.33 to 14.93 μm.

When there is a gradual rise in factors such as feed or depth of cut, as shown in Fig. 10, it is seen that the optimal values are achieved for circular runout. However, as the values continue to climb, the findings start to show a reverse trend. This phenomenon is readily seen in circular runout and sometimes in roundness. These changes may be caused by the impact of cutting parameters on roundness and circular runout, as well as other indirect elements such as cutting forces or vibrations that occur during the cutting process.

3.4. Signal-to-noise ratio approach

In the Taguchi analysis, the smaller-the-better S/N ratio was chosen to measure the performance characteristics levels against parameter factors and then determine the best roundness and circular runout value. The S/N ratio is a measure of the desirable signal compared with the undesired random noise, and it indicates the quality of the experimental data. Typically, an investigation of the S/N ratio involves three groups of performance characteristics: those that are better when they are lower, those that are better when they are higher, and those that are better when they are at a nominal level. The goal of this study was to minimize the out of roundness and the circular runout, i.e., the lower is the better is applied (Boy et al., 2015).

The S/N ratios of the out-of-roundness and circular runout data are calculated based on the experimental results. The ratios mentioned are utilized to ascertain the most favorable amount of each variable. These ratios are derived utilizing Eq. (1) according to the lower-the-better approach, as outlined by Asiltürk and Akkuş (2011). In this methodology, Y_i represents the observed data during the experiment, and n represents the number of experiments conducted. Table 6 displays the outcomes of the S/N ratio for both out-of-roundness and circular runout. The lower SNR value obtained for out-of-roundness and circular runout indicates the optimal cutting parameters that would be employed.

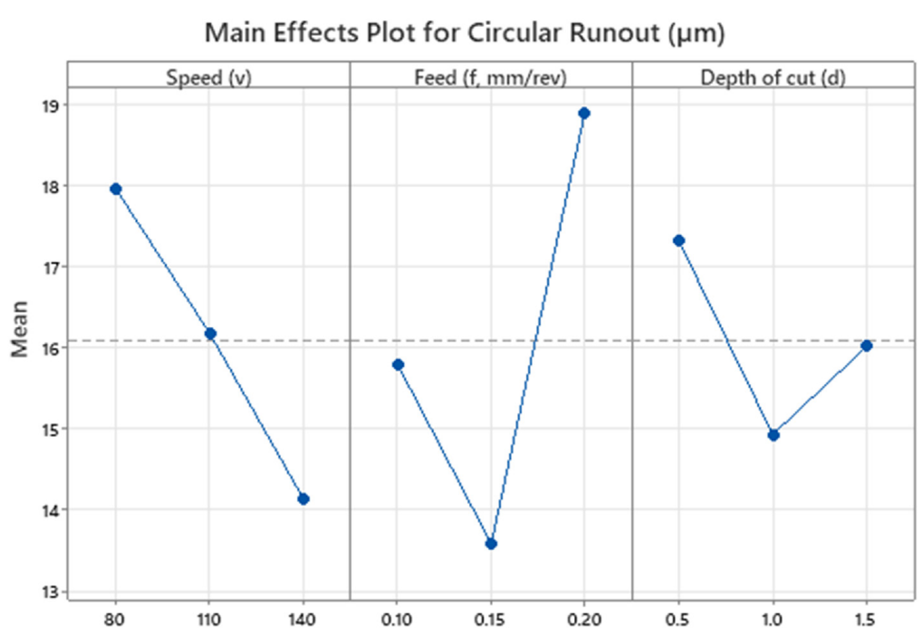


Fig. 10. Main effects plots for circular runout.

Table 6. The calculated signal-to-noise Ratios via the Taguchi Method.

No.	Speed (v, m/min)	Feed (f, mm/rev)	Depth of cut (d, mm)	Out-of-roundness S/N ratio	Circular runout S/N ratio
1	80	0.10	0.5	−21.26	−28.49
2	80	0.10	1.0	−19.41	−24.44
3	80	0.10	1.5	−16.29	−20.74
4	80	0.15	0.5	−20.93	−24.34
5	80	0.15	1.0	−19.09	−24.06
6	80	0.15	1.5	−14.07	−25.42
7	80	0.20	0.5	−19.12	−23.83
8	80	0.20	1.0	−17.39	−27.85
9	80	0.20	1.5	−14.85	−28.24
10	110	0.10	0.5	−20.71	−24.72
11	110	0.10	1.0	−18.38	−21.32
12	110	0.10	1.5	−15.22	−19.22
13	110	0.15	0.5	−18.76	−27.79
14	110	0.15	1.0	−14.77	−20.09
15	110	0.15	1.5	−12.25	−23.69
16	110	0.20	0.5	−17.27	−25.38
17	110	0.20	1.0	−15.16	−26.79
18	110	0.20	1.5	−15.25	−28.38
19	140	0.10	0.5	−18.54	−26.43
20	140	0.10	1.0	−16.53	−24.65
21	140	0.10	1.5	−18.84	−25.79
22	140	0.15	0.5	−16.15	−18.57
23	140	0.15	1.0	−14.40	−19.14
24	140	0.15	1.5	−13.72	−19.71
25	140	0.20	0.5	−18.65	−23.25
26	140	0.20	1.0	−14.05	−22.20
27	140	0.20	1.5	−15.23	−26.53

$$\frac{S}{N(\eta)} = -10.\log\left[\frac{1}{n}\cdot\sum_{i=1}^{0} Y_i^2\right] \tag{1}$$

Fig. 11 depicts the graphs of the signal-to-noise ratios that were computed for the roundness measurements during the turning process of the cylindrical shafts. Table 7 displays the S/N ratios of the factors at each level. Various values (Δ) of the S/N ratio range from the highest to the lowest. Hence, after analyzing the S/N ratios presented in Table 7 and Fig. 11, it was determined that the most favorable cutting circumstances to minimize out-of-roundness were achieved at a cutting speed (v) of 140 m/min, a feed (f) of 0.15 mm/rev, and a depth of cut (d) of 1.5 mm.

An analysis of variance (ANOVA) was employed to determine the design characteristics that have a significant impact on the roundness. This analysis was conducted with a confidence level of 95%. Table 8 displays the ANOVA findings for the out-of-roundness. This table provides information on the degree of freedom (DF), the sum of squares (SS), mean square (MS), F values (F), probability (P), and percentage-contribution ratio (PCR) for each factor. A *P* value of 0.05 indicates a high level of statistical significance for the source of the related answer. The significant levels of the variables were determined by considering the F-ratios and their PCR. According to Table 8, the depth of cut is the most influential variable for the out-of-roundness values, with a PCR of 43.12%. The feed has a PCR of 16.68%, and the speed has a PCR of 14.10%. These results validate the order of significance indicated in Table 7. The improvement in roundness with increasing cutting speed is significant. This suggests that higher cutting speeds result in smoother and more precise machined surfaces. There is also a trend towards better roundness with higher feeds, this effect may be close to the effect of an increasing vector of velocities. The depth of cut shows a clear significant correlation with out-of-roundness in this data set.

Fig. 12 depicts the graphs of the S/N ratios that were computed for circular runout while turning the cylindrical shafts. Table 9 displays the S/N ratios of the variables for each level, as referenced in Table 6. The table displays the difference (Δ) in the S/N ratio between the highest and lowest values. Based on the S/N ratios provided in Table 9 and Fig. 12, the most favorable cutting conditions for the circular runout were determined to be v = 140 m/min, f = 0.15 mm/rev, and d = 1 mm.

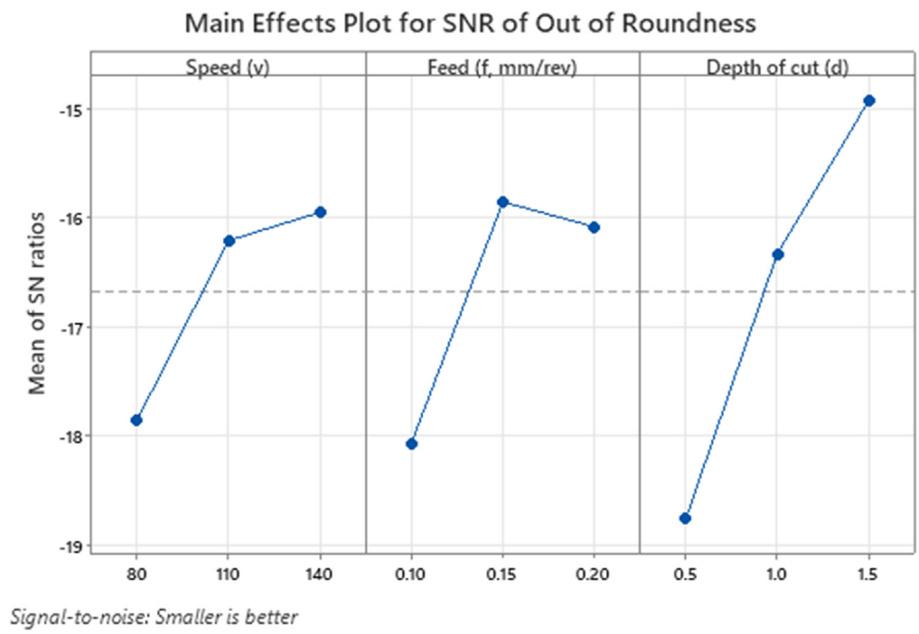


Fig. 11. Signal-to-noise ratio of out of roundness measurements.

Table 7. Response table for signal-to-noise ratios of the out of roundness.[a]

Level	Speed (v)	Feed (f, mm/rev)	Depth of cut (d)
1	−17.85	−18.07	−18.76
2	−16.21	−15.85	−16.33
3	−15.95	−16.08	−14.93
Difference Δ	1.90	2.22	3.83
Rank	3	2	1

[a] Smaller is better.

An analysis of variance (ANOVA) was employed to determine the design characteristics that have a substantial impact on circular runout. This analysis was conducted with a confidence level of 95%. The ANOVA results for the circular runout are shown in Table 10, which indicates that the most effective variable for the circular runout value is the feed with the PCR of 18.57%, the cutting speed has 9.61% but based on the P values ($P < 0.05$) provided in the ANOVA using Minitab, it appears that there are no significant differences between depth of cut and circular runout, within the given range as shown in Table 10. These results confirm the order of importance shown in Table 9.

In both roundness and circular runout, lower absolute S/N values are desirable as they indicate better performance. Looking at the S/N values, Figs. 11 and 12, it can be seen that lower S/N ratios for both roundness and circular runout result from higher cutting speeds. A lower S/N ratio for both resulted from medium feed, especially for circular runout. The S/N values provide a quantitative measure of the trade-off between the mean performance (average out of roundness or circular runout) and variability (standard deviation) in the data. Lower S/N values indicate that the mean performance is relatively high compared with the variability, implying better overall machining performance. When evaluating the S/N ratios, it is essential to consider not only the average values but also the variability or consistency in the results. A higher S/N ratio signifies that the machining process is more stable and less prone to variations.

Table 8. Analysis of variance for out-of-roundness.

Source	DF	Seq SS	Contribution (PCR)	Adj SS	Adj MS	F value	P value
Speed (v)	2	14.84	14.10%	14.84	7.419	5.41	0.013
Feed (f, mm/rev)	2	17.55	16.68%	17.55	8.776	6.39	0.007
Depth of cut (d)	2	45.36	43.12%	45.36	22.679	16.52	0.000
Error	20	27.45	26.09%	27.45	1.373		
Total	26	105.20	100.00%				

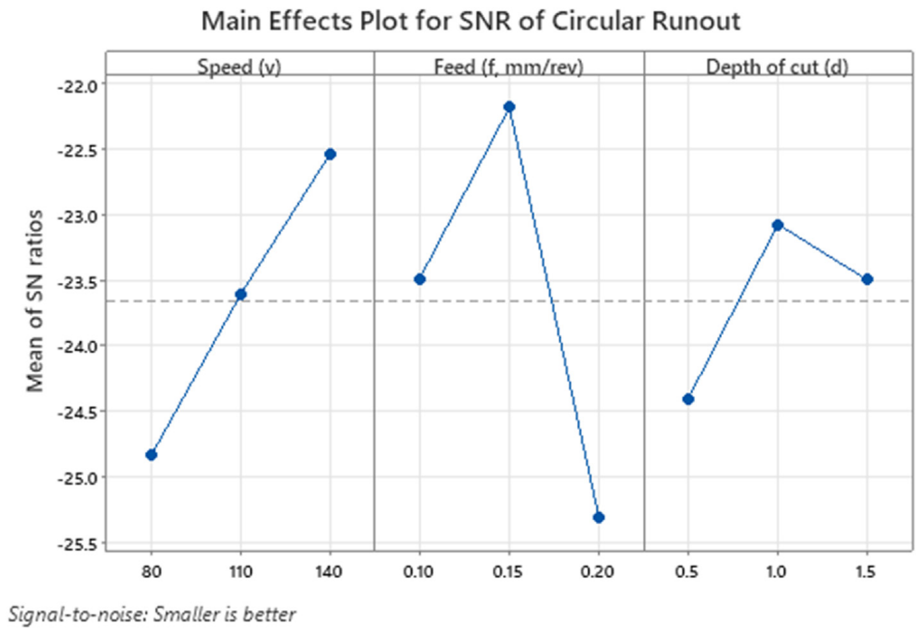


Fig. 12. Signal-to-noise ratio of circular runout measurements.

Table 9. Response table for circular runout signal-to-noise ratios.[a]

Level	Speed (v)	Feed (f, mm/rev)	Depth of cut (d)
1	−24.84	−23.49	−24.40
2	−23.60	−22.18	−23.07
3	−22.53	−25.31	−23.50
Difference Δ	2.31	3.12	1.33
Rank	2	1	3

[a] Smaller is better.

The results suggest that increasing cutting speed generally leads to improved roundness and circular runout, which is reflected in lower S/N values. Feed also has an influence, with higher feeds generally improving circular runout. The depth of cut shows a high impact on the out-of-roundness but does not have an effect in a circular runout during the given range. It's important to note that these trends can vary depending on the specific machining process and the material being cut, so further experimentation and analysis may be needed to optimize cutting parameters for specific applications.

3.5. Conclusions

Manufacturers face many challenges to obtain a product of high value and good efficiency at the lowest possible price to suit the customer. This paper explored the impact of cutting parameters on roundness, and circular runout in turning operations, highlighting the importance of achieving high dimensional accuracy in manufacturing processes. Roundness and runout are geometric tolerances that control the radial deviations of cylindrical or spherical features. Machining parameters, such as cutting speed, feed, depth of cut, tool geometry, and coolant, can affect the quality of these tolerances by influencing the surface roughness, dimensional accuracy, and form error of the machined parts. Generally, the use of high cutting speed, low feed, and low depth of cut leads to better values of out-of-roundness and circular runout. However, based on the experiments and measurements conducted in this research, the following information is concluded between machining parameters, roundness, and circular runout:

Table 10. Analysis of variance for circular runout.

Source	DF	Seq SS	Contribution (PCR)	Adj SS	Adj MS	F value	*P* value
Speed (v)	2	66.55	9.61%	66.55	33.27	1.41	0.267
Feed (f, mm/rev)	2	128.67	18.57%	128.67	64.34	2.73	0.090
Depth of cut (d)	2	25.88	3.73%	25.88	12.94	0.55	0.586
Error	20	471.70	68.09%	471.70	23.58		
Total	26	692.79	100.00%				

(a) Higher cutting speed tends to improve both roundness and circular runout.
(b) The higher depth of cut tends to improve roundness in this research but does not have any effect on circular runout.
(c) In turning operation, the use of high cutting speed (140 rev/min), medium feed (0.15 mm/rev), and high depth of cut (1.5 mm) is recommended to obtain better roundness, the same recommended values in cutting speed and feed are used in circular runout but the depth of cut was at medium level of it (1 mm) to obtain the best result of circular run out.
(d) The depth of cut is the most significant factor affecting the roundness but the feed and speed sequentially are the most effective parameters on circular runout.

These relations are not absolute, as they may vary depending on the material properties, machine tool characteristics, and measurement methods. Therefore, it is important to optimize the machining parameters for each specific application to achieve the desired roundness and runout.

Ethical statement

There is no ethical statement.

Funding statement

There is no funding for the researcher.

Author contribution/Author credit statement

Enas A. Taha: Conceived and designed the study, contributed to data analysis and interpretation, performed investigations, contributed to methodology development, conducted statistical analysis, and drafted the article.

Mona A. AbouEleaz: Contributed to data analysis and interpretation, performed investigations, and revised the article.

Ossama B. Abouelatta: Conceived and designed the study, contributed to data analysis and interpretation, contributed to methodology development, conducted statistical analysis, supervised the study, critically revised the article, and provided final approval of the version to be published.

Fatma A. Elerian: Conceived and designed the study, contributed to data analysis and interpretation, performed investigations, contributed to methodology development, conducted statistical analysis, supervised the study, and critically revised the article.

Conflict of interest

There are no conflicts of interest.

References

Abeni, A., Cappellini, C., Seneci, G., Del Prete, A., Attanasio, A., 2024. Tool run-out in micro-milling: development of an analytical model based on cutting force signal analysis. Micromachines 15, 305.

Abouelatta, O., Madl, J., 2001. Surface roughness prediction based on cutting parameters and tool vibrations in turning operations. J. Mater. Process. Technol. 118, 269−277.

Ameta, G., Lipman, R., Moylan, S., Witherell, P., 2015. Investigating the role of geometric dimensioning and tolerancing in additive manufacturing. J. Mech. Des. 137, 111401.

Balasubramaniyan, S., Selvaraj, T., 2017. Application of integrated Taguchi and TOPSIS method for optimization of process parameters for dimensional accuracy in turning of EN25 steel. J. Chin. Inst. Eng. 40, 267−274.

Beruvides, G., Quiza, R., Rivas, M., Castaño, F., Haber, R.E., 2014. Online detection of run out in microdrilling of tungsten and titanium alloys. Int. J. Adv. Manuf. Technol. 74, 1567−1575.

Bissacco, G., Hansen, H.N., Slunsky, J., 2008. Modelling the cutting edge radius size effect for force prediction in micro milling. CIRP Annal. 57, 113−116.

Boy, M., Ciftci, I., Gunay, M., Ozhan, F., 2015. Application of the Taguchi method to optimize the cutting conditions in hard turning of a ring bore. Materiali in Tehnologije 49, 765−772.

Chen, Y., Lu, J., Deng, Q., Ma, J., Liao, X., 2022. Modeling study of milling force considering tool runout at different types of radial cutting depth. J. Manuf. Process. 76, 486−503.

Chou, C.-Y., Chen, C.-H., Yang, C.-C., Wu, C.-C., 2005. Application of bivariate parameter design to the optimization of the operating conditions of a turning process. Int. J. Prod. Res. 43, 5229−5240.

Çiçek, A., Kivak, T., Samtaş, G., 2012. Application of Taguchi method for surface roughness and roundness error in drilling of AISI 316 stainless steel. Strojniški vestnik-J. Mechan. Eng. 58, 165−174.

Elerian, F.A., 2022. Filters used for roundness error evaluation: an experimental comparison study. MEJ-Mansoura Eng. J. 47, 1−13.

Elerian, F., Helal, W.M., Aboueleaz, M., 2021. Methods of roundness measurement: an experimental Comparative study. J. Mech. Eng. Res. Develop. 44, 173−183.

Elsadek, A.A., Gaafer, A.M., Mohamed, S., 2020. Optimization of roundness error in hard turning of AISI H13 tool steel. EGTRIP 17, 53−61.

Feng, H.-Y., Menq, C.-H., 1994. The prediction of cutting forces in the ball-end milling process—II. Cut geometry analysis and model verification. Int. J. Mach. Tool Manufact. 34, 711−719.

Gao, W., Haitjema, H., Fang, F., Leach, R., Cheung, C., Savio, E., Linares, J.-M., 2019. On-machine and in-process surface metrology for precision manufacturing. CIRP Annals 68, 843−866.

Islam, M.N., Anggono, J., Pramanik, A., Boswell, B., 2013. Effect of cooling methods on dimensional accuracy and surface finish of a turned titanium part. Int. J. Adv. Manuf. Technol. 69, 2711−2722.

Jirapattarasilp, K., Kuptanawin, C., 2012. Effect of turning parameters on roundness and hardness of stainless steel: SUS 303. AASRI Procedia 3, 160−165.

Ko, J.H., Cho, D.-W., 2005. Determination of cutting-condition-independent coefficients and runout parameters in ball-end milling. Int. J. Adv. Manuf. Technol. 26, 1211−1221.

Li, G., Li, S., Zhu, K., 2020. Micro-milling force modeling with tool wear and runout effect by spatial analytic geometry. Int. J. Adv. Manuf. Technol. 107, 631—643.

Liao, Z., Schoop, J.M., Saelzer, J., Bergmann, B., Priarone, P.C., Splettstößer, A., et al., 2024. Review of current best-practices in machinability evaluation and understanding for improving machining performance. CIRP J. Manuf. Sci. Technol. 50, 151—184.

Manivasagam, R., Richard, S., 2023. Minimizing the roundness variation in automobile brake drum by using taguchi technique. Smart Grids Smart Cities 2, 95—104.

Martín-Béjar, S., Trujillo, F., Bermudo, C., Sevilla, L., 2019. Cutting parameters influence on total run-out of dry machined UNS A97075 alloy parts. Procedia Manuf. 41, 835—842.

Meadows, J.D., 2009. Geometric Dimensioning and Tolerancing: Applications, Analysis & Measurement (Per ASME Y14. 5-2009). American Society of Mechanical Engineers.

Mishra, A., Gangele, A., Israr, M., 2013. Application of taguchi approach in the optimization of roundness of cylindrical bars of AISI 1045 steel. Int. J. Basic Appl. Sci. 2, 186—194.

Némedi, I., Sekulić, M., Radlovački, V., Hodolič, J., Hadžistević, M., Takács, M., 2017. A method for determining roundness and actual form of circular workpiece cross sections. Acta Polytechnica Hungarica 14, 169—184.

Rafai, N., Islam, M., 2009. An investigation into dimensional accuracy and surface finish achievable in dry turning. Mach. Sci. Technol. 13, 571—589.

Rafai, N.H., Islam, M.N., 2011. Comparison of dry and flood turning in terms of dimensional accuracy and surface finish of turned parts. Elect. Eng. Appl. Comput. 90, 501—513.

Rico, L., Naranjo, A., Noriega, S., Martínez, E., Vidal, L., 2010. Effect of cutting parameters on the roundness of cylindrical bars turned of 1018 steel. In: Proceedings of the 15th Annual International Conference on Industrial Engineering: Theory, Applications and Practice, Mexico City, Mexico. October 17-20, pp. 131—136.

Rivière-Lorphèvre, E., Filippi, E., 2009. Mechanistic cutting force model parameters evaluation in milling taking cutter radial runout into account. Int. J. Adv. Manuf. Technol. 45, 8—15.

Saglam, H., Unsacar, F., Yaldiz, S., 2005. An experimental investigation as to the effect of cutting parameters on roundness error and surface roughness in cylindrical grinding. Int. J. Prod. Res. 43, 2309—2322.

Scippa, A., Grossi, N., Campatelli, G., 2013. Milled surface generation model for chip thickness detection in peripheral milling. Procedia CIRP 8, 450—455.

Şeker, U., Kurt, A., Çiftçi, İ., 2004. The effect of feed rate on the cutting forces when machining with linear motion. J. Mater. Process. Technol. 146, 403—407.

Singaravel, B., Marulaswami, C., Selvaraj, T., 2016. Analysis of the effect of process parameters for circularity and cylindricity errors in turning process. Appl. Mech. Mater. 852, 255—259.

Soenoko, R., Suprapto, A., Choiron, M.A., 2017. Surface roughness and roundness optimization on turning process of aluminium alloy with Taguchi method. J. Mech. Eng. 14, 87—96.

Tzeng, C.-J., Yang, Y.-K., 2008. Determination of optimal parameters for SKD11 CNC turning process. Mater. Manuf. Process. 23, 363—368.

Tzou, G.-J., Chen, D.-Y., Hsu, C.-Y., 2006. Application of Taguchi Method in the Optimization of Cutting Parameters for Turning Operations. Department of Mechanical Engineering, Lunghwa University of Science and Technology, Taiwan, (ROC).

Wan, M., Zhang, W., Qin, G., Tan, G., 2007a. Efficient calibration of instantaneous cutting force coefficients and runout parameters for general end mills. Int. J. Mach. Tool Manufact. 47, 1767—1776.

Wan, M., Zhang, W., Tan, G., Qin, G., 2007b. New algorithm for calibration of instantaneous cutting-force coefficients and radial run-out parameters in flat end milling. Proc. IME B J. Eng. Manufact. 221, 1007—1019.

Wan, M., Zhang, W.-H., Dang, J.-W., Yang, Y., 2009. New procedures for calibration of instantaneous cutting force coefficients and cutter runout parameters in peripheral milling. Int. J. Mach. Tool Manufact. 49, 1144—1151.

Wan, M., Zhang, W.-H., Yang, Y., 2011. Phase width analysis of cutting forces considering bottom edge cutting and cutter runout calibration in flat end milling of titanium alloy. J. Mater. Process. Technol. 211, 1852—1863.

Wang, S.-M., Chen, D.-F., Jang, M.-C., Tsooj, S., 2012. Development of micro milling force model and cutting parameter optimization. Trans. Nonferrous Metals Soc. China 22, s851—s858.

Yang, S., Tong, J., Liu, Z., Ye, Y., Zhai, H., Tao, H., 2023. Experimental study on the roundness of deep holes in 7075 aluminum alloy parts by two-dimensional ultrasonic elliptical vibration boring. Micromachines 14, 2185.

Zhang, D., Mo, R., Chang, Z., Sun, H., Li, C., 2016. A study of computing accuracy of calibrating cutting force coefficients and run-out parameters in flat-end milling. Int. J. Adv. Manuf. Technol. 84, 621—630.

Zheng, H., Li, X., Wong, Y., Nee, A., 1999. Theoretical modelling and simulation of cutting forces in face milling with cutter runout. Int. J. Mach. Tool Manufact. 39, 2003—2018.