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Geometry Characterization of Products Results in the Finishing Process Using Centerless Belt Grinding Machine

Karakteristik Geometri Produk Hasil Proses Akhir dengan Mesin *Centerless Belt Grinding*

Jesika Erventy Osman, Sofia Debi Puspa*, Triyono, Hary Munandar
Mechanical Engineering Study Program, Faculty of Industrial Technology, Universitas Trisakti, Jakarta 11440, Indonesia

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Abstract

The centerless belt grinding machine that was previously designed at the Department of Mechanical Engineering at Universitas Trisakti can be used for finishing machining products. However, it is not yet known how the machine will perform on the geometric characteristics of the product as a result of the finishing process with a centerless belt grinding machine. The geometric characteristics here are the results of measurements in cylindricality, roundness, and surface roughness. This research aims to determine the machine's performance and whether there are significant differences in the centerless belt grinding finishing process. Control chart analysis is used to determine the consistency of engine performance, and a comparison of the feed speed is used to determine engine performance. Next, data processing was carried out using the paired sample t-test statistical test to determine whether there were significant differences between the turning and milling processes. The consistency test results indicated good performance achieved at a maximum speed of 25.47 mm/minute (angle 12°) for cylindrical, roundness, and surface roughness measurements. The statistical test results of the paired t-test between the turning and grinding processes showed significant differences, as indicated by the P-value (0.00) < ∝ (0.05) on cylindricality, roundness, and surface roughness.

Keywords: centerless belt grinding, cylindrical, roundness, surface roughness.

***SDGs*:**

Abstrak

Mesin gerinda tanpa sabuk *(centerless belt grinding)* yang telah dirancang sebelumnya di Jurusan Teknik Mesin Universitas Trisakti dapat dimanfaatkan untuk melakukan finisihing pada produk pemesinan. Namun belum diketahui performa kinerja mesin terhadap karakteristik geometri produk dari hasil proses dengan mesin Centerless Belt Grinding. Karakteristik geometri disini merupakan hasil pengukuran dalam kesilindrisan, kebulatan, dan kekasaran permukaan. Tujuan penelitian ini adalah untuk mengetahui performa mesin serta mengetahui apakah ada perbedaan yang signifikan dari proses pemesinan gerinda. Analisis peta kendali digunakan untuk mengetahui konsistensi kinerja mesin dan perbandingan kecepatan makan untuk mengetahui performa mesin. Selanjutnya dilakukan pengolahan data menggunakan uji t berpasangan untuk mengetahui adanya perbedaan yang signifikan antara proses bubut dan gerinda. Hasil uji konsistensi pada pengukuran kesilindrisan, kebulatan, dan kekasaran permukaan menunjukkan terdapat konsistensi dengan kinerja baik dicapai pada kecepatan maksimum 25,47 mm/menit (sudut 12°). Hasil uji t berpasangan menunjukkan terdapat perbedaan yang signifikan dengan nilai P-value (0,00) < ∝ (0,05) dalam kesilindrisan, kebulatan, dan kekasaran permukaan.

Kata Kunci: *centerless belt grinding*, kesilindrisan, kebulatan, kekasaran permukaan.

*Correspondence Author
email : sofia.debi.puspa@trisakti.ac.id

1. INTRODUCTION

In general, various processes are required to make a final product, including machining processes that can achieve narrow tolerances and high surface finish. The machining process is carried out after other processes, for example, in the casting and metal forming processes. However, each machine tool has specific capabilities to achieve dimensional, shape, and surface roughness accuracy. Therefore, multiple machining processes are often required to achieve the product specifications set by the designer. Some of them are turning, drilling, milling, and grinding processes (Erameh *et al.*, 2016).

Steel is critical in the industrial world, particularly in producing tool and system components. One such component is the shaft, which is manufactured through a machining process involving turning and cylindrical grinding. Modern machining processes pose environmental challenges. Turning is a manufacturing method widely used to create engineering components with a circular cross-section. This method is achieved when the tool moves parallel to the rotational axis of the workpiece. The lathe process is used to reduce the workpiece's diameter to the desired size. The grinding process is generally used as a finishing method to improve the quality of the geometry and smooth the workpiece's surface for a specific purpose (Abolghasem and Mancilla-Cubides, 2022).

The Production Process Laboratory of the Mechanical Engineering Department, Universitas Trisakti, has a belt grinding machine without a flashlight. This machine has guide rollers, tools, and control panels. The range of workpiece dimensions that can be machined is up to 50 mm. However, the consistency and performance of this belt grinding machine without a flashlight still needs to be fully understood. Previous studies have yet to explore centerless belt grinding machines, particularly regarding cylindrical, roundness, and surface roughness.

Research conducted by Ariyanto et al. used a horizontal lathe with mild steel test objects with a diameter of 30 mm and the length of the test object is 200 mm (Ariyanto, Husman and Dharta, 2017). The cutting tool is made of carbide material with a cutting-edge radius of 0.8 mm. The process of cutting the workpiece is carried out using the three-jaw chuck method without a center. The depth of cut varied between 0.4mm and 0.04mm, with a feeding speed and the process of cutting the test object at 0.077 mm/rotation. The cylindrical test object that has been cut is measured using a bench center tool and a dial indicator with a significant shift of the measurement point of 10°. The results obtained after testing eight lathes with one specimen each using six position points are the tolerance values of IT (International Tolerance) 10-11.

Hamdi et al., carried out research on the roundness of aluminum shafts using a roundness tester machine with a test material with a diameter of 28 mm and a length of 310 mm (Hamdi, Arief and Prayitno, 2015). Turning was carried out with a constant spindle rotation of 200 rpm and cylinder turning with varying feed speeds v_f= 20 mm/minute, 40 mm/min, and 70 mm/min. The method for measuring the roundness of the surface of a lathe object uses the circle method. The value of the smallest roundness deviation and the average for each variation of feeding speed, then at a feeding speed of 20 mm/min, the smallest roundness deviation value after deducting the correction factor of the Roundness Tester Machine tool is obtained -0.017 mm to 0.023 mm, and the average value is 0. 0037mm.

The study conducted by Jiang et al., analyzed the impact of different levels of surface roughness on a titanium alloy (Jiang *et al.*, 2022). By using various models of abrasive belts to grind the surface repeatedly, they were able to determine that when the roughness level falls between Ra 0.4 µm and 0.2 µm, a higher linear speed results in a decrease in compressive residual stress and an increase in surface morphology defects. However, when the roughness level is Ra 0.2 µm or less, grinding enhances the surface morphology, leading to an increase in compressive residual stress with an increase in the feed rate. It's important to note that an increase in linear speed results in a decrease in surface hardness.

A study conducted by Mamuka et al. researched the design of the belt mount sanding machine using a 125 Watt electric drive motor resulted in the design of a sanding machine (Mamuka, Zuldesmi and Maukar, 2022). The machine uses a Sanyo pump motor, and experiments measuring time and speed showed that using a belt grinding machine significantly speeds up the sanding process compared to manual sanding.

According to Rofarsyam, a belt system sanding machine can be created by modifying a regular grinding machine into a rotating belt system (Rofarsyam, 2018). The manufacturing process involves designing the machine, manufacturing its components, assembling the machine, testing it, and analyzing the results. The belt system sanding machine is powered by a 0.5 HP electric motor, which rotates at 1400 rpm. The belt-turning transmission system uses a 1:40 reducer and a pulley belt. The Deerfos 80 Hv brand sandpaper is used in this machine. The sanding test results show that the machine achieves a surface roughness of N8, which is comparable to the results of sanding with a grinding machine in the machine shop. The sanding capacity achieved by this machine is also the same as that of the grinding machine, which is 0.271 mm^3/second.

The design of a sanding machine using a grip belt from the sides of the sandpaper serves to scrape a light surface, such as wooden beams, light metal, and aluminum. From the results of the calculations and design, it is concluded that the sanding machine (belt sander) uses an electric motor with a specification of 1 hp (2800 rpm) using a pulley with a ratio of 2:1. This machine is also designed to carry out work processes in horizontal and vertical positions. The results of the study concluded that the Pulley ratio greatly influences the desired speed for a machine design that is repeatedly wrong in size and design that does not match its function (Setiawan, Pramono and Waluyo, 2023).

In a study conducted by Pandiyan et al., the impact of various parameters such as cutting speed, force, polymer wheel hardness, feed, and grit size on the abrasive belt grinding process was explored (Pandiyan *et al.*, 2020). A statistical regression approach was employed to model material removal. The research findings suggest that the grit size parameter has the most significant effect. Based on the proposed regression model, it is possible to determine the precise level of process parameters for achieving the desired material removal without needing physical belt grinding experiments.

In this research, the improvement of the geometric characteristics of the lathe processing results will be studied, which will be further processed using a centerless belt grinding machine. Cylindrical, roundness, and surface roughness will be checked in this case. Cylindrical is the smaller value of the deviation caused by the cutting process. At the same time, roundness is the uniformity of the distance between an object's center point and the outermost point (David, Mufarrih and Istiqlaliyah, 2018). Surface roughness is a measure/value of the roughness of the surface of a material or the high and low of a material surface as measured from a reference point (Budiana *et al.*, 2020). This roughness is also a component of texture in a surface. These indicators are analyzed from the measurement results after the turning and grinding process using a centerless belt grinding machine. The problem to be investigated is the consistency and performance of a belt grinding machine without a flashlight on the test object's roundness, cylindrical, and surface roughness after the lathe process of the pulley shaft on the conveyor belt.

Therefore, in this study, we will examine the performance and consistency of a centerless belt grinding machine for roundness, cylindrical, and surface roughness. Additionally, the author will use statistical analysis to investigate the differences in product geometry measurement results. The statistical test used is the Paired sample t-test to determine any significant difference before and after the finishing process of centerless belt grinding, following the stages of the turning process.

2. METHODOLOGY

2.1. Research Flowchart

The research began with a literature study and experimental design. There is a need for a lathe process to equalize the results to be ground and determine the lathe process parameters required for the cutting process.

After that, cylindrical, roundness, and surface roughness measurements were carried out. Furthermore, the grinding process parameters for the following grinding process are determined. The exact measurements are taken as in the lathe process. After obtaining the measurement results of the lathe and grinding machine, the data is analyzed to determine the consistency performance of the grinding machine and the differences in geometry resulting from the lathe and grinding process using statistical analysis methods. The research flowchart is shown in Figure 1.

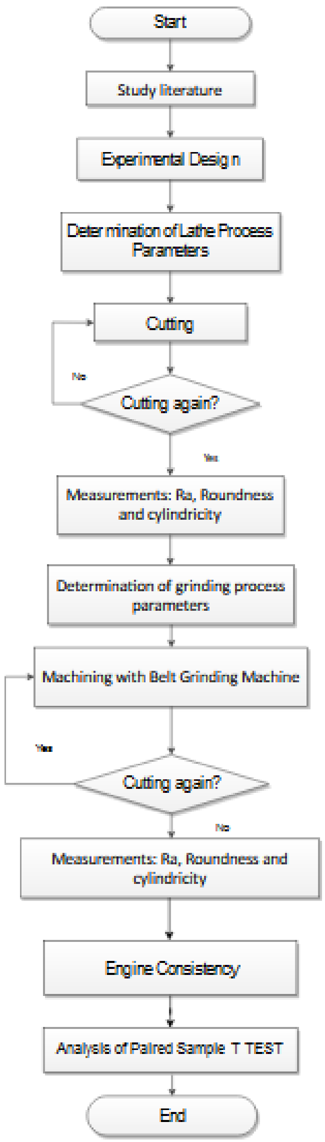

Figure 1. Research flowchart.

2.2. Research Material

2.1.1. Test Object Material

The specimen material used is S45C steel. S45C steel is a medium carbon steel, containing between 0.44% C, 0.57 – 0.69% Mn, 0.013-0.037%P, 0.033-0.038%S, 0.16-0.20%Si (Aziz and Mutaqin, 2023). Its carbon content allows the steel to be partially hardened by suitable heat treatment. The description of the sample size of the test object is:

- Initial diameter: 25 mm
- Specimen length:150 mm
- Final diameter: 23 mm
- Number of specimens: 30 pcs

2.1.2. Lathe Chisel Material

The cutting tool used to carry out the workpiece cutting process is a VBMT 160408HQ carbide insert lathe with a cutting speed of 120 m/min. VBMT 160408HQ Lathe Chisel can be seen in Figure 2.

Figure 2. Chisel lathe VBMT 160408HQ.

2.1.3. Grinding Stone

The type of grinding stone used is Grit 800 belt sander, as seen in Figure 3. The following are the specifications of the grinding belt used:

- Type: sanding belt
- Grit size: 800
- Dimensions: 1700mm x 31mm
- Weight: 7 grams

Figure 3. Sanding belt.

2.1.4. Lathe

The lathe used is located at Production Process Laboratory Universitas Trisakti, as seen in

Figure 4. This machine has the following specifications:

- Brand: United Ltd. Trojan
- Model: Universal Lathe
- No. Series: C 404 T
- Year: 1996
- Voltage: 380 V
- Length of machine flashlight: 1100 mm
- Rotating diameter: 530 mm

Figure 4. Lathe machine.

The process of cutting the test specimen is carried out with a depth of cut (a) of 1 mm, feeding movement (f) of 0.15 mm/rev, and cutting speed (v) of 0.06 m/min.

2.1.5. Centerless Belt Grinding Machine

The grinding machine used is a grinding machine located at the Production Process Laboratory Universitas Trisakti, which can be seen in Figure 5 with the following specifications:

- Belt drive motor power: 0.18 kW
- Rotate the belt drive motor: 433.5 rpm
- Dimensions (length x width x height): 1000 x 400 x 710 (mm)

Figure 5. Centerless belt grinding machine.

2.1.6. Screw Micrometer Measuring Instrument

The tool used to measure the diameter of the test object is a screw micrometer which can be seen in Figure 6 with the type of micrometer screw (thread), and the accuracy is 0.01 mm.

Figure 6. Screw micrometer.

2.1.7. Punch Former

The punch former is a workpiece clamping tool in the form of a round or cylindrical rod that is relatively small on a flat grinding machine. The working principle of the punch former is that the workpiece is clamped with a chuck; the punch former is usually used for the workpiece to be ground into various shapes such as cylindrical, flat, inclined plane, triangle, quadrangle, hexagon, octagon, and others. The punch former image can be seen in Figure 7.

Figure 7. Punch former.

2.1.8. Dial Indicator

A dial indicator or dial gauge is a measuring instrument with a measurement scale with a very small value, with an accuracy of 0.01 mm. This measuring instrument has a shape similar to an analog clock, which has two to three hands, which can be seen in Figure 8.

2.1.9. Surface Roughness Measuring Instrument

The Roughness Tester is the instrument for measuring the surface roughness of the material used. After the test object has finished turning and grinding, the surface roughness data is collected using the Surfest Mitutoyo tool. However, the test object's surface must be cleaned beforehand until dry. The specifications of this measuring instrument are as follows and can be seen in **Figure 9**.

- Brand: Mitutoyo
- Type: Surfest SJ-301
- Accuracy: 0.02 μm

Figure 8. Dial indicator.

Figure 9. Roughness tester.

2.3. Shewhart Control Chart

The NACA series airfoil was created and developed by the National Advisory Committee for Aerodynamics (NACA) Shewhart first created control charts for manufacturing processes through statistical sampling procedures. It can also see the results of a production process in good and stable condition or products produced according to standards (Malindzakova, Čulková and Trpčevská, 2023). In control charts, lines are needed that limit the specifications of the production process results. In general, control charts consist of three horizontal lines (Faraz, Saniga and Montgomery, 2019).

a. The centre line, the line that shows the mean or average value of the quality characteristics plotted on the control chart.
b. Upper Control Limit (UCL), the line above the centre line indicates the upper control limit.
c. Lower control limit (LCL), the line below the centre line which indicates the lower control limit.

The lines are determined from historical data. Shewhart uses a normal distribution curve (Gaussian distribution) with μ as the center line, indicating the average value of the distribution of process characteristics, and $\pm\sigma$, which is converted into UCL and LCL as the basis. In this research, the control chart used is the Individual and Moving Range Control Chart (I-MR). I-MR is used if the number of observations from each subgroup is 1 ($n = 1$).

2.4. Centerless Belt Grinding Parameters

Several process parameters affect the centerless belt grinding process, as shown in Figure 10.

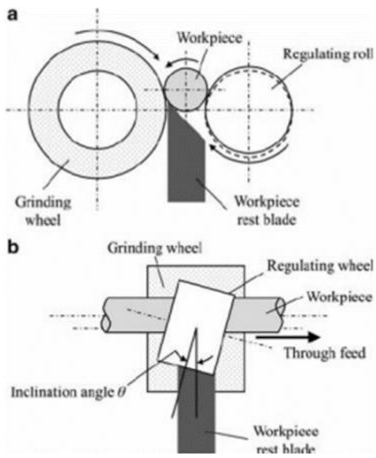

Figure 10. Centerless belt grinding parameters (Leonesio, Bianchi and Safarzadeh, 2019).

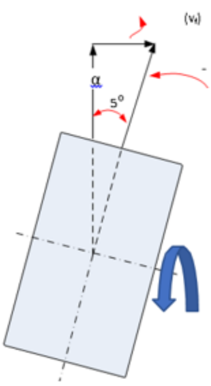

Figure 11. Illustration of the influence of adjustment wheel tilt on the amount of feeding speed V.

The grinding process parameters include grinding belt diameter, grinding belt width, grinding belt rotation, cutting depth, and workpiece diameter (Leonesio, Bianchi and Safarzadeh, 2019). Figure 11 illustrates the influence of the tilt of the control wheel on the feed speed V in mm/minute.

2.5. Paired Sample t-Test

The paired sample t-test is a technique used to compare the mean of two groups of people or cases that are matched or compares the mean of a single group at two different points in time. This test aims to determine whether there is an average difference between the two samples before and after treatment. A paired sample refers to a sample with the same subject undergoing two different treatments or measurements. However, normal distribution is a necessary assumption for a standard t-test (Ranger *et al.*, 2023).

In this study, we will use the paired sample t-test to determine whether the results of the product geometry measurements show a significant difference before and after undergoing the centerless belt grinding finishing process following the lathe process stages. It is important to note that this test has specific requirements that must be met:

1) The data owned by the subject is interval or ratio data.
2) Both groups of paired data are normally distributed

The paired t-test is a hypothesis-testing method where the data used is not independent (in pairs). This test obtains two kinds of sample data from the first and second treatment data. The hypothesis can be written as follows (Montolalu and Langi, 2018):

$$H_0: \mu_1 - \mu_2 = 0 \quad (1)$$

$$H_1 : \mu_1 - \mu_2 \neq 0 \quad (2)$$

3. RESULTS AND DISCUSSION

The research was implemented by analyzing the geometric shapes of the lathe results with grinding results. From the data obtained and the data processing carried out, the geometric differences from the results of the turning and grinding processes can be seen, which include cylindrical, roundness, and surface roughness.

Based on the experimental results of cutting S45C steel with the following cutting conditions:

- Spindle rotation (n): 1200 rpm
- Cutting speed (Vf): 0.1 mm/s
- Depth of cut (a): 1 mm
- Feeding motion (f): 0.15 mm/rotation
- Chisel type: VBMT 160408HQ Lathe Chisel

Diameter measurements were made at both ends of the specimen, where location 1 was 10 mm from the end of the first side, and location 2 was 10 mm from the end of the second side. Then, the average diameter of the measurement results of the two locations is calculated. The results of measuring the diameter of the test object are shown in Table 1.

Table 1. The result of measuring the diameter of the lathe process.

Sample	Diameter (mm) Spot 1	Diameter (mm) Spot 2	Average (mm)
1	23.36	23.24	23.30
2	23.37	23.24	23.30
3	23.36	23.23	23.29
4	23.37	23.24	23.30
⋮	⋮	⋮	⋮
28	23.39	23.23	23.31
29	23.37	23.24	23.30
30	23.38	23.25	23.31
Average			23.30

In addition, measurements of cylindrical values, roundness, and surface roughness were conducted due to the lathe machining process. Prior to the measurements, the test object was cleaned with alcohol and a clean cloth to ensure a clean surface without any dirt. The circular section of the test object was divided into eight parts, while each section in the horizontal section was given ten measurement points at a 15 mm distance. The workpiece was clamped using a punch former, and a dial indicator stylus was attached to one side of the test object's surface. The dial indicator measurements were taken at each horizontal point, and eight measurements were carried out. The measurement values for cylindrical, roundness, and surface roughness are displayed in Table 2.

Table 2. Lathe process results measurement data.

Table of Experimental Data Lathe Results			
Sample	**Cylindrical (mm)**	**Roundness (mm)**	**Surface Roughness (μm)**
1	0.27	0.180	2.1
2	0.18	0.143	1.9
3	0.51	0.248	2.5
4	0.37	0.208	1.6
⋮	⋮	⋮	⋮
28	0.40	0.200	1.7
29	0.64	0.243	2.2
30	0.52	0.197	2.5

The surface smoothing process after the lathe process uses a Centerless Belt Grinding machine and a grinding stone, namely Sanding belt Grid 800. The surface smoothing process on 30 sample specimens with different angle variations is as follows: specimen 1-3 using an angle of 1.5°, specimen 4-6 using an angle of 3°, until specimen 28-30 using an angle of 15°

The grinding process is carried out with one feeding on each test object, and the belt sanding is replaced at every different angle. After the grinding process, measurements are taken on the test object after the turning process, as seen in Table 3.

Table 3. Grinding process results measurement data.

Experimental Data Table of Grinding Process Results			
Sample	**Cylindrical (mm)**	**Roundness (mm)**	**Surface Roughness (μm)**
1	0.25	0.1670	1.4
2	0.30	0.2108	0.9
3	0.19	0.1283	1.3
4	0.32	0.2033	2.0
⋮	⋮	⋮	⋮
28	0.30	0.182	1.5
29	0.14	0.117	2.3
30	0.23	0.092	2.4

3.1. Centerless Belt Grinding Machine Consistency

The consistency of results from the centerless belt grinding machine was determined using a statistical approach, specifically utilizing the Shewhart control chart. This control chart is used to see the processing capabilities of a system. Control charts have several analysis methods. However, in this study, only one observation was made of each test object characteristic, so this study used I-MR (Individual-Moving Range) analysis. Moving Range is the distance or range between one data point and the previous data point. Analysis was carried out using SPSS software for each measurement of cylindricity, roundness, and surface roughness.

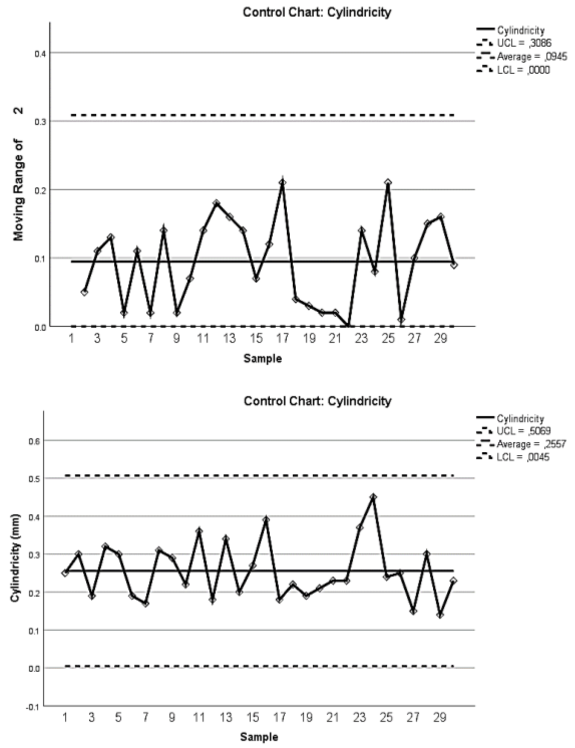

Figure 12. Moving range and individual cylindrical charts.

Based on the results of determination and visualization using Shewhart control charts, I-MR graphs show that cylindricity, roundness, and surface roughness do not exceed the control limits, or the graph moves within the specified limits, namely in the LCL and UCL range. Consequently, the graphs are statistically controlled, and the results for the cylindrical, roundness and surface roughness values generated from the centerless belt grinding machine are consistent. Figure 12 is an example of the results of the Shewhart graph on cylindricity. To produce more homogeneous product production and produce high quality products the use of statistical methods of sample quality control helps ensure the consistency of the technological process (Alekseeva, Perelygina and Kolyshkina, 2018).

3.2. Centerless Belt Grinding Machine Performance Analysis

Machining the test object using centerless belt grinding, a finishing process is carried out with a variation of the workpiece angle 30. On a centerless belt grinding machine, the angle that can be achieved to carry out the grinding process is 0 to 15˚. Variations of the angles used are 1.5˚, 3˚, 4.5˚, 6˚, 7.5˚, 9˚, 10.5˚, 12˚, 13.5˚ and 15˚. The amount of angle is set through the tilt of the adjusting wheel (regulating wheel). Of course, the angle size affects the final workpiece, which can be seen through cylindrical, roundness, and surface roughness measurements. The feed speed of the test object with vertical linear velocity can be calculated from the angle determined by the formula, as in equation (3) below:

$$Cs = \frac{\pi \times d \times n}{1000} \quad (3)$$

$$= \frac{\pi \times 90 \times 433.5}{1000}$$

$$= 122.507 \text{ mm/min}$$

where:

Cs : cutting speed (mm/min)

d : diameter of regulating wheel (mm)

n : rotation per minute

And below the horizontal feed speed of the test object can be determined using the formula below. So that the velocity value can be obtained from each angle, as shown in Table 4.

$$v_f = Sin\, 5A.\ Cs \quad (4)$$

Table 4. Average value of cylindrical, roundness and surface roughness of grinding results with feeding speed.

Angle (˚)	Average cylindrical (mm)	Average Roundness (mm)	Average Surface Roughness (µm)	Velocity (vf) (mm/min)
1.5	0.25	0.17	1.20	3.21
3	0.27	0.20	1.99	6.41
4.5	0.26	0.16	1.79	9.61
6	0.25	0.19	1.95	12.80
7.5	0.27	0.27	1.81	15.99
9	0.26	0.26	1.97	19.16
10.5	0.22	0.21	2.33	22.32
12	0.35	0.35	2.66	25.47
13.5	0.21	0.04	0.13	28.60
15	0.22	0.13	0.13	31.71

The Table 4 shows the average value of cylindrical, roundness, and surface roughness of each corner, where each angle is the average value of 3 samples of test objects with a ratio of feeding speed.

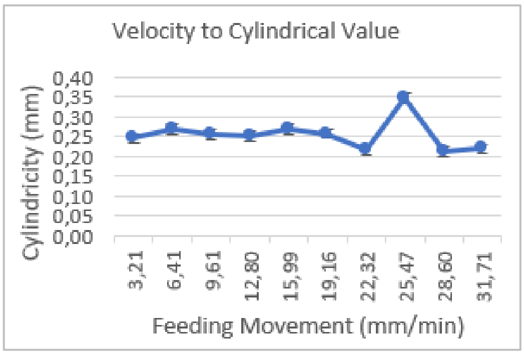

Figure 13. Graph of speed against cylindrical value.

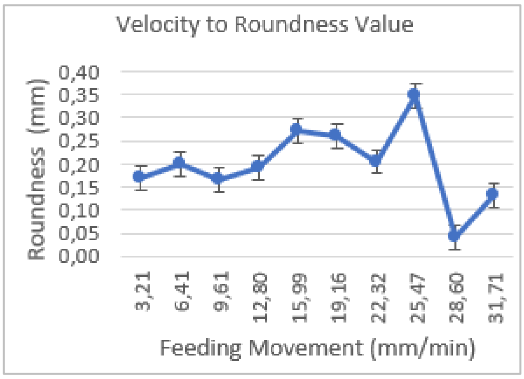

Figure 14. Graph of speed against roundness value.

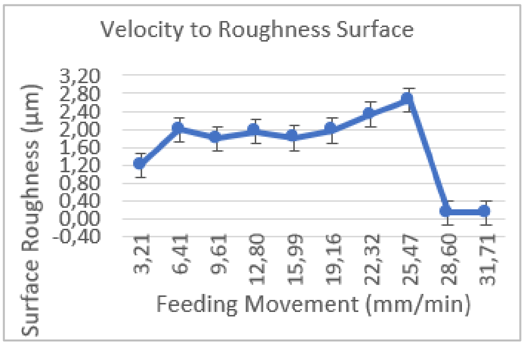

Figure 15. Graph of speed against surface roughness value.

Based on Figure 13, Figure 14 and Figure 15, the results show that the smallest cylindrical, roundness, and roughness values are at a speed of 28.6 mm/min (angle 13.5˚) on an average of 25.26 and 27 specimens with a cylindrical value of 0.21 mm, the value roundness of 0.04 mm, and a roughness value of 0.13 µm.

In comparison, the highest cylindrical, roundness, and roughness values are at a speed of 25.47 mm/min (angle 12°) on the average of test objects 22, 23, and 24 with a cylindrical value of 0.35 mm, a roundness value of 0.35 mm, and a roughness value of 2.66 μm. In general, the greater the feeding speed, the greater the cylindrical value (David, Mufarrih and Istiqlaliyah, 2018). The graph shows that good engine performance can be achieved up to a speed of 25.47 mm/min (angle 12°).

3.3. Lathe Process Normality Test

After measuring the results of the lathe, statistical analysis was carried out. The statistical analysis used in this study was the paired sample t-test with SPSS software. However, before carrying out the paired sample t-test, a normality test will be carried out as a condition for testing the paired sample t-test. The normality test was conducted to determine whether the obtained variables were normally distributed. The following is a hypothesis on the normality test.

H_0: The data follows a normal distribution.

H_1: The data does not follow a normal distribution.

Table 5. Lathe process normality test.

Tests of Normality						
	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Cylindrical	0.112	30	0.200*	0.964	30	0.401
Roughness Surface	0.148	30	0.092	0.96	30	0.304
Roundness	0.157	30	0.56	0.963	30	0.361

The normality test results from the lathe measurement can be seen in Table 5, which shows that the Sig. or p-value (0.401) > α (0.05) for cylindrical; in roundness, the p-value is obtained 0.304 > α (0.05); and for surface roughness, the p-value (0.361) > α was obtained by the Shapiro Wilk test. So, the lathe results on cylindrical, roundness, and surface roughness are insufficient evidence at the 5% level to reject H_0.

3.4. Grinding Process Result Normality Test

We conducted a statistical analysis to compare the results of the turning process with those of the grinding process. Before the analysis, we needed to determine whether the data from the grinding process followed a normal distribution. We performed a normality test using the Shapiro-Wilk method in SPSS software based on the measurement results from the lathe process. The hsypothesis for the normality test is as follows.

H_0: The data follows a normal distribution.

H_1: The data does not follow a normal distribution.

Table 6. Grinding process normality test.

Tests of Normality						
	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Cylindricity	0.132	30	0.191	0.954	30	0.214
Roughness Surface	0.113	30	0.200*	0.980	30	0.833
Roundness	0.116	30	0.200*	0.979	30	0.785

The results of the normality test for measurements taken from the grinding machine are displayed in Table 6. The Shapiro-Wilk test shows that the Sig. or p-value (0.214) is greater than α (0.05) for the cylindrical. Similarly, for roundness, the p-value is 0.833, which is also greater than α (0.05). Surface roughness yielded a p-value of 0.785, greater than α. Therefore, based on these results, there is insufficient evidence to reject H_0 at the 5% level for cylindrical, roundness, and surface roughness.

3.5. Paired Samples t-Test Analysis

After the cylindrical, roundness, and surface roughness results are tested for normal distribution, it can be continued with the paired sample t-test. This test is to find out the average comparison of two paired groups. In this study, a comparison was made between lathe measurement data and grinding machine measurement data. The paired sample t-test was conducted using SPSS software with a significance level of α = 5%.

The data from cylindrical measurements were compared before and after the lathe and grinding processes to determine any significant differences. The hypothesis test of paired sample t-test for cylindrical is as follows:

H_0: There is no significant difference between the lathe and grinding processes' results in cylindrical.

H_1: There is a significant difference between the results of the lathe and grinding processes regarding cylindrical.

Table 7 shows the value of Sig. (2 tailed) or a significance value of 0.000 where the significance value < α (5%) so that H_0 is rejected. It can be said that there is a significant difference between the results of the lathe and grinding processes regarding cylindrical.

Table 7. Paired t-test results of cylindrical.

Paired Samples Test					
	95% Confidence Interval of The Difference				
	Lower	Upper	t	df	Sig. (2-failed)
Cylindrical	0.104	0.201	6.4	29	0.00

In the same way, the process is carried out to determine whether there are significant differences between the lathe and grinding processes' results in roundness and surface roughness. The Paired t-test results for roundness can be seen in Table 8, which shows the value of Sig. (2 tailed) or p-value of 0.000 less than α (5%) so that H_0 is rejected. Hence, there is a significant difference in the roundness of the lathe process and the roundness of the grinding process.

Table 8. Paired t-test results of roundness.

Paired Samples Test					
	95% Confidence Interval of The Difference				
	Lower	Upper	t	df	Sig. (2-failed)
Roundness	0.05	0.09	7.5	29	0.00

Table 9. Paired t-test results of surface roughness.

Paired Samples Test					
	95% Confidence Interval of The Difference				
	Lower	Upper	t	df	Sig. (2-failed)
Surface Roughness	0.13	0.41	4.1	29	0.00

Table 9 displays the results of the Paired t-test for surface roughness. The significance value, or Sig. (2 tailed), is 0.000, indicating that the p-value is less than α (5%). Therefore, the null hypothesis (H_0) is rejected. So, there is a significant difference between the surface roughness results of the lathe and grinding processes.

Overall, the differences between turning and grinding results are obtained regarding cylindricity, roundness, and surface roughness, indicating improvements in product geometry. This proves that the designed machine has the same performance as abrasive machines, which function as a finishing process.

4. CONCLUSION

The control chart analysis using the I-MR method shows that the centerless belt grinding machine has good consistency because the resulting control chart is within the LCL and UCL limits and is statistically controlled. Based on the analysis of the feed speed of the grinding process, good engine performance can be achieved up to a speed of 25.47 mm/min (angle 12°). The paired t-test results reveal significant differences between the turning and grinding processes while measuring cylindricity, roundness, and surface roughness. These differences suggest an enhancement in product geometry and an improvement in geometric quality, specifically a 61% increase in cylindricity, a 70% increase in roundness, and an 86% improvement in surface roughness smoothness.

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