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Optimization of 3D Printing Parameters Using the Taguchi Method to Improve Dimensional Precision

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Abstract

The combination of parameters in the product printing process with Polylactic Acid (PLA) material using the ANET ET4 PRO 3D printer is carried out to obtain optimal parameters to produce accurate dimensions in the printing process. The most popular type of 3D printer is the Fused Deposition Modeling (FDM) type, which uses melted plastic raw materials to form products. In the existing printing process, the accuracy of the dimension is the main problem owned by users of this 3D printer technology. Especially when these products have to be assembled into a mechanism. The resulting accuracy is greatly influenced by the selection of process parameters used during the printing process. The parameter optimization process using the Taguchi method was chosen because this method is very good at overcoming deviations from the target so that the best quality of the product can be achieved. The optimization process of this parameter will be carried out using a ring-shaped specimen with an outer diameter of 30 mm, an inner diameter of 20 mm, and a height of 20 mm. This deviation in the size of the inner diameter of the ring would be the reference for measuring the quality of the printed object. From the experiments, the most optimal level values for each factor were as follows: the Nozzle Temperature was 200 °C, the Bed Temperature was 62 °C, the Room Temperature was 34 °C, the Infill Percentage was 40%, the Layer Height was 0.25 mm, the Printing Speed was 20 mm⁄s.

Keywords: Additive Manufacturing, 3D Printer, Polylactic Acid, Taguchi Method, Accuracy, Optimization.

1. Introduction

The 3D printer is a very helpful technology in turning a design into a prototype. One of the reasons for using this 3D printer is the ability to print objects in detail in a relatively fast processing time [1]. This will be very helpful in making products, especially mechanical systems which are a combination of several components, as shown in Figure 1. In the design process, making prototypes becomes very important as a basis for evaluating the design [2]. With a 3D printer, the time to make a prototype becomes shorter. In the past, the process of making prototypes of mechanical components was carried out using manufacturing machines, such as milling machines, lathes, grinding machines, etc. which would take longer and cost more. In the design process, after a prototype has been made, an evaluation process will be carried out. This evaluation process will produce the improvements needed to improve the performance of the tool or the ergonomic level of the product. With the hope that the resulting product will have more perfect in quality.

If the prototyping process is carried out using manufacturing machines rather than 3D printers, it will take more time to get the perfect product, especially if the evaluation process is carried out more than once. So, the existence of a 3D printer is very helpful in the prototyping process.

Figure 1. Prototype of Planetary Gearbox

Even so, the process of making prototypes using a 3D printer still has limitations and shortcomings. In the

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process, several problems will arise that will ultimately affect the quality of the components. For example, dimensions that are not accurate due to deformation after the process ends, non-uniform shape and the level of smoothness of the product that is not as expected due to the selection of inappropriate parameters [3], [4], the strength of the printed product against suboptimal bending force [5], and others parameter. Some of these things will affect the process of making prototypes, especially those consisting of several components that are assembled into a mechanical system. The simplest example is when making a shaft that must be attached to a hole. Mechanically, the shaft must be able to rotate freely in the existing hole. The process of making prototypes for these assembled objects is not easy using a 3D printer. Several parameters must be combined properly to get optimal results.

Several studies have been carried out related to the use of 3D printers in the prototype manufacturing process, especially to make products that have intricate details and require a relatively fast time to produce, such as making cast patterns using a 3D printer to speed up and simplify the process [6], [7], [8]. The casting pattern manufacturing process is applied not only in the manufacturing industry but also in the medical area which is called bone tissue engineering [9]. To obtain optimal process results, some researchers have researched parameter optimization to obtain dimensional accuracy. Hasdiansah optimized the parameters in the 3D printing process with PLA Food Grade material to get an accurate response. Hasdiansah's research focus is on the high level of accuracy of printed objects [10], similar research has also been carried out by Christiliana with the same research focus but using different shapes of objects [11]. In another study conducted by Pamasaria, parameter optimization was carried out to obtain the best response results on the size of length, width, and height [12]. The focus of this study is to find the best combination of parameters to obtain prints with the most accurate length, width, and height sizes. Pristiansyah also researched to find the optimal value of the parameters of the printing process using a 3D printer. The difference from this study is the use of flexible materials. Pristiansyah's research focus is to obtain the accuracy of the outer size in the XYZ direction of the printed object [13].

Some of the existing studies have all focused on the accuracy of the outer dimension of the printed workpiece. While a mechanical system will consist of shaft objects and holes. Therefore, in this study, the level of accuracy of hole size was chosen as a reference in determining the optimal parameters in the printing process using a 3D printer. This is because by using a hole base, in making an assembled object the hole size tolerance must have the same level of tolerance quality or higher [14].

2. Research Method

In this study, the design of the test object was carried out by using SolidWorks 2020. The dimension of the outer diameter was 30 mm, the inner diameter was 20 mm and the height was 20 mm as shown in Figure 2.

Figure 2. The design of the test object

PLA was the material which was used, while the machine used to print products was an ANET ET4 PRO 3D printer.

Figure 3. ANET ET4 PRO 3D printer

The process of measuring the dimensions of the specimen used a Mitutoyo dial calliper 0-150 mm which has an accuracy of 0.02 mm (Figure 4.).

Figure 4. Mitutoyo Dial Caliper

In this investigation, the Taguchi Method was used as the optimization method. Taguchi's method emphasizes more on quality aspects. In addition, the Taguchi method uses the Design of Experiment (DoE) as a tool to make the product more robust and not affected by noise. This DoE was used to reduce variations in process and product quality characteristics [15], [16], [17].

Selection of process parameters in the form of factors and experimental levels based on experience in using 3D printers. There were six parameters used in the process and five levels for each factor. These parameters were the Nozzle Temperature, the Bed Temperature, the Room Temperature, the Infill Percentage, the Layer Height, and the Printing Speed. The DoE Taguchi scenario used L_{25} Orthogonal Array (OA). Table 1 shows the level of each parameter. Table 2 shows the

DoE on the Taguchi L_{25} OA which was a combination of each factor and level.

Table 1. The Factors and Levels Parameters

Level	Nozzle temp.	Bed Temp.	Room Temp.	Infill Percent.	Layer Height	Printing Speed
1	200	61	32	20	0.2	20
2	202	62	34	40	0.225	25
3	204	63	36	60	0.25	30
4	206	64	38	80	0.275	35
5	208	65	40	100	0.3	40

Table 2. The DoE Taguchi L_{25} OA

Nozzle temp.	Bed Temp.	Room Temp.	Infill Percent.	Layer Height	Printing Speed
200	61	32	20	0.2	20
200	62	34	40	0.225	25
200	63	36	60	0.25	30
200	64	38	80	0.275	35
200	65	40	100	0.3	40
202	61	34	60	0.275	40
202	62	36	80	0.3	20
202	63	38	100	0.2	25
202	64	40	20	0.225	30
202	65	32	40	0.25	35
204	61	36	100	0.225	35
204	62	38	20	0.25	40
204	63	40	40	0.275	20
204	64	32	60	0.3	25
204	65	34	80	0.2	30
206	61	38	40	0.3	30
206	62	40	60	0.2	35
206	63	32	80	0.225	40
206	64	34	100	0.25	20
206	65	36	20	0.275	25
208	61	40	80	0.25	25
208	62	32	100	0.275	30
208	63	34	20	0.3	35
208	64	36	40	0.2	40
208	65	38	60	0.225	20

The Taguchi method with DoE using Orthogonal Arrays aimed to obtain maximum information with a minimum number of investigations [18]. The Signal-to-Noise Ratio (S/N ratio) was evaluated to achieve a statistical measure of process performance. In determining the SNR, depending on the desired output quality, 3 types of S/N ratio can be used, namely: smaller is better, nominal is better, and bigger is better [19]. The formula for those 3 types of S/N ratio is shown in the equation below.

Smaller is better

$$\frac{S}{NR} = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \quad (1)$$

Nominal is better

$$\frac{S}{NR} = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right] \quad (2)$$

Larger is better

$$\frac{S}{NR} = 10log_{10}\frac{\mu^2}{\sigma^2} \quad (3)$$

In this investigation, the type of S/N ratio used was *Smaller is Better*. This type has the peculiarity that the greater the SNR value, the better the quality of the results obtained [20].

3. Result and Discussion

From the experimental results using the parameters shown in Table 2, the average response was obtained from 3 specimens for each level as shown in Table 3 below.

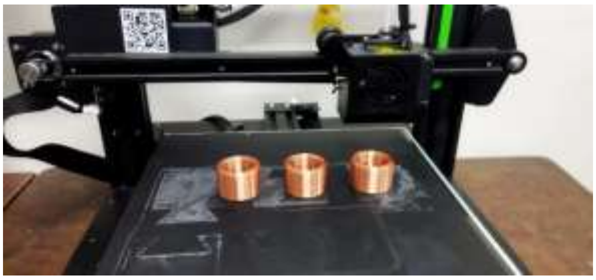

Figure 5. the experiment results

Figure 5 above shows the experiment results in printing the product using an ANET ET4 PRO 3D printer in PLA material. Each combination of the factors would be printed in 3 products.

Table 3. Experimental results

No.	Average Response (mm)	Object I (mm)	Object II (mm)	Object III (mm)
1	20.03	20.03	20.04	20.02
2	20.013	20.01	20.01	20.02
3	20.08	20.07	20.08	20.09
4	20.037	20.03	20.04	20.04
5	20.163	20.18	20.16	20.15
6	20.01	19.99	20.02	20.02
7	20.097	20.09	20.12	20.08
8	20.173	20.17	20.15	20.2
9	20.067	20.06	20.06	20.08
10	20.047	20.04	20.05	20.05
11	20.26	20.26	20.28	20.24
12	20.023	20.03	20.04	20
13	20.037	20.04	20.05	20.02
14	20.063	20.07	20.07	20.05
15	20.06	20.06	20.08	20.04
16	20.043	20.04	20.06	20.03
17	20.093	20.12	20.08	20.08
18	20.087	20.11	20.08	20.07
19	20.107	20.12	20.1	20.1
20	20.133	20.12	20.14	20.14
21	20.063	20.06	20.08	20.05
22	20.17	20.2	20.17	20.14
23	20.133	20.13	20.14	20.13
24	20.2	20.22	20.18	20.2
25	20.107	20.1	20.12	20.1

Then by using the quality characteristics of Smaller is better to analyze the data, the S/N ratio was obtained to identify the factors that influence the variation of response. Table 4 below is a response Table for the S/N ratio of the analysis results using the Taguchi Method for each factor at 5 different levels.

Table 4. Response for Signal to Noise Ratios (Smaller is better)

Level	Nozzle Temp.	Bed Temp.	Room Temp.	Infill Percent.	Layer Height	Printing Speed
1	-26.0486	-26.0558	-26.055	-26.0541	-26.0688	-26.0532
2	-26.0547	-26.055	-26.0486	-26.05	-26.0667	-26.0593
3	-26.0589	-26.0648	-26.0872	-26.0512	-26.0483	-26.057
4	-26.0607	-26.0616	-26.0538	-26.0504	-26.0541	-26.0699
5	-26.0789	-26.0648	-26.0573	-26.961	-26.0639	-26.0624
Delta	0.03	0.01	0.04	0.05	0.02	0.02
Rank	3	6	2	1	4	5

Figure 6, is about the S/N ratio for each factor in every level, those are the same data presented in Table 4. The biggest value in the S/N ratio is the better quality of the product.

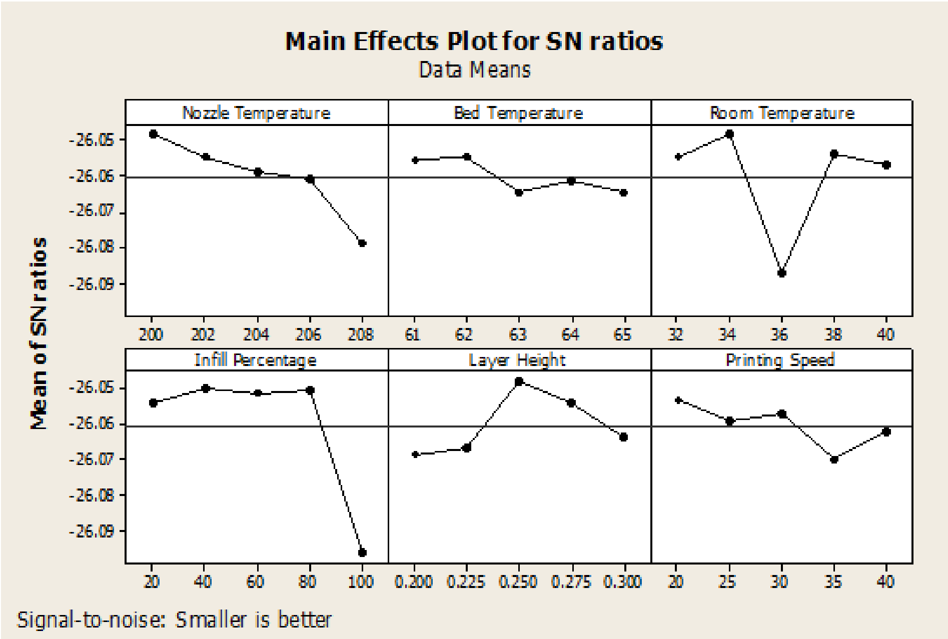

Figure 6. S/N ratio chart for each factor

Table 5. Response for Means (Smaller is better)

Level	Nozzle Temp.	Bed Temp.	Room Temp.	Infill Percent.	Layer Height	Printing Speed
1	20.0647	20.0813	20.0793	20.0773	20.1113	20.0753
2	20.0787	20.0793	20.0647	20.068	20.1067	20.0893
3	20.0887	20.102	20.154	20.0707	20.064	20.084
4	20.0927	20.0947	20.0767	20.0687	20.0773	20.114
5	20.1347	20.102	20.0847	20.1747	20.10	20.0967
Delta	0.07	0.02	0.09	0.11	0.05	0.04
Rank	3	6	2	1	4	5

Table 5 shows the value of the average size deviation from the results of measuring a hole diameter of 20 mm. This value is also displayed on a graph shown in Figure 7. Here, the lowest deviation value the better quality of the product. Both Table 4 and Table 5 above show that the most significant factor in this investigation is Infill Percentage (rank 1) followed by Room Temperature, Nozzle Temperature, Layer Height, Printing Speed, and the last is Bed Temperature.

From the results of the analysis using Taguchi, on the graph the largest S / N ratio value shows the most optimal level value in the printing process because it uses the Smaller the better method [21], [22]. As for the re-examination, it could be done by looking at the measurement results in Table 5 and Figure 7. Table 5 and Figure 7. show the value of the size deviation from the reference size of 20 mm. From these results, using the Smaller the better method, the smallest deviation value shows the most optimal level value in the printing process. In the S/N ratio chart for each factor, the highest value on the Nozzle Temperature is 26.0486, or refers to level 1 of that factor. For rechecking it can be seen on the graph the deviation of the size values shown in Figure 6.

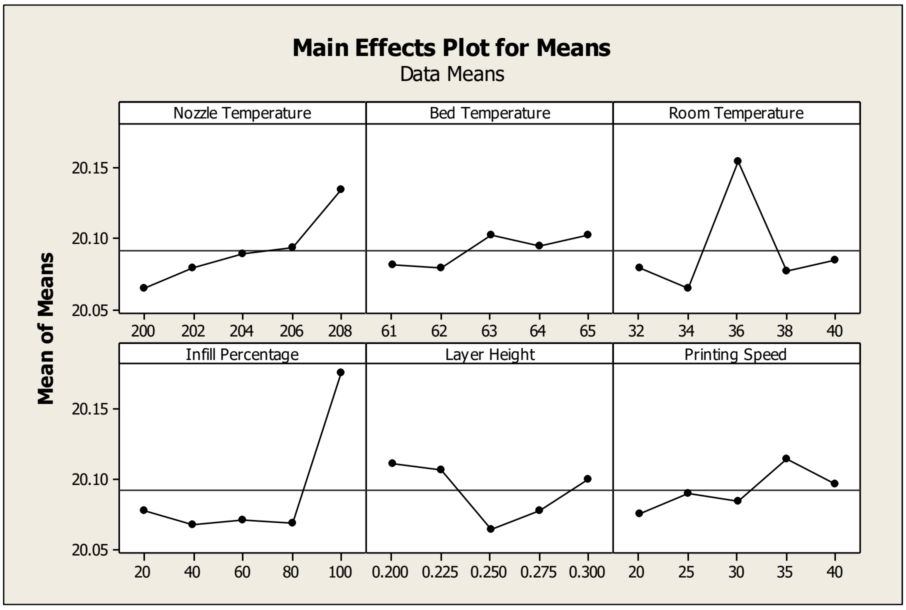

Figure 7. Means of dimensional deviation

Here the reference is the lowest value of the size deviation that occurs because it uses the Smaller the better method. In this chart, the lowest size deviation value in the Nozzle Temperature factor is 20.0647, or refers to level 1 of the factor. So, the optimum value of the Nozzle Temperature factor is level 1. Here is the highest value of each factor:

i. The next factor is the Bed Temperature. The highest value in the S/N ratio of this factor is -26.055 which refers to level 2.
ii. In the Room Temperature factor, the highest value in the S/N ratio of this factor is -26.0486 which refers to level 2.
iii. For Infill Percentage, the highest value in the S/N ratio of this factor is -26.05 which refers to level 2.
iv. Meanwhile, the highest value in the S/N ratio of Layer Height is -26.0483 which refers to level 3.
v. The last factor is the Printing Speed, the highest value in the S/N ratio of this factor is -26.0532 which refers to level 1.

4. Conclusion

From the results of the research on optimizing the 3d printing parameters in the product printing process with PLA material to obtain accurate hole dimensions, it can be concluded that the optimal value of the process parameters to obtain accurate dimensions at a diameter within 20 mm is the *Nozzle Temperature:* 200° C, the *Bed Temperature*: 62° C, the *Room Temperature*: 34° C, the *Infill Percentage*: 40 %, the *Layer Height*: 0.25 mm, the *Printing Speed:* 20 mm/s. Furthermore, further research will be carried out to validate the results using a different number of iterations.

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