



## OPTIMIZATION OF LASER CUTTING ENGRAVING PERFORMANCE ON ACRYLIC MATERIALS USING TAGUCHI METHOD APPROACH

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### ABSTRACT

Today's laser cutting machining process is often utilized in large industries as well as individual and student science projects. Acrylic is one of the materials in which the processing involves a lot of laser cutting, but currently many laser cutting processes, especially the low low powers, are not optimally optimized. In this study, the author wants to optimize laser cutting with the power of 6.5 watts using the Taguchi optimization method on solid black acrylic material with a thickness of 3 mm, with the reference to the surface roughness value of the workpiece after being subjected to the laser cutting process using the Ra unit. The control factors included are laser distance, laser power, cutting speed and , ancooling time. The experimental process was carried out 27 times with replication of measurements 2 times. The best result from the experiment was the roughness measurement value of 0.782  $\mu\text{m}$  while the mean roughness value was 2.271  $\mu\text{m}$ . After condexperimenting is known that the best results are obtained with a laser distance factor of 20.6mm, cutting speed of 70 mm/min, laser power owatt wa ts ,and cooling time,e of 10 s. Meanwhile, the effect of factors on the surface roughness results is the laser distance 27%, cuttingneedof eed 40.9laserr over 18.9coolingolingme 7.05%. After calibrating the laser cutting, the cutting accuracy increased from  $\pm 1\text{mm}$  to  $\pm 0.4\text{ mm}$  o,r an increase of 60%, with an average final dimension measurement of 24.87 mm.

**Keywords:** laser cutting, acrylic, optimization, surface roughness

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# 1. INTRODUCTION

The machining process widely used by the manufacturing industry today is laser cutting engraving. Laser cutting is a technology used to cut to a certain depth on the workpiece using a laser as the cutting tool. Laser cutting operates by focusing the output of a high-power laser through the optics. Lasers on the market today work by cutting materials according to the CNC or Gcode to produce workpieces with good quality and good precision (Saputro & Darwis, 2020).

Currently, production costs using laser cutting have become more affordable, so the use of laser cutting is spreading widely, not only in large-scale industrial activities but also in education, small businesses, to hobbies carried out at home.

Acrylic is a transparent thermoplastic, often used in sheet form due to its lightweight and its shatter resistance which is mainly used as an economical alternative to glass. Acrylic does not contain traces of bisphenol-A, a potentially harmful combination which can be found in polycarbonate. Acrylic is a strong and lightweight material. The density of acrylic ranges from 1.17-1.20 g/cm<sup>3</sup> which is half smaller than glass. The impact strength of acrylic is stronger than glass and polystyrene. (Eshwar, 2016)

Acrylic can transmit up to 92% of visible light with a thickness of 3 mm and with a refractive index of 1.4905 at 589.3 nm it can reflect up to 4% of the light from its surface. Acrylic material itself is currently widely used as a substitute for glass because it is lighter and not easily broken. The most important properties of acrylic are weather resistance, strong, weight as easy to get, and considerably cheap in terms of transportation and installation costs.

The result of the dimensional calibration process is carried out by calculating the comparison of the initial setting value and the dimensional result before calibration with the desired dimensional result with the x setting value

$$\text{overs} \frac{d1}{s1} : \frac{d2}{x}$$

Where:

d1 = dimension of the initial result before calibration

d2 = desired dimensional result

s1 = initial setting value on the GRBL laser

x = setting value to be entered

Table 1. Value of Laser Cutting Settings

| No | X-axis         | Y-axis         | Accuracy |
|----|----------------|----------------|----------|
| 1  | 161,29 step/mm | 181,29 step/mm | ±25 mm   |
| 2  | 83,87 step/mm  | 83,87 step/mm  | ±1 mm    |
| 3  | 80,645 step/mm | 80,645 step/mm | ±0,4 mm  |

Calibration is carried out to obtain the desired dimensions of the cutting results with the best possible accuracy.

Optimization of the acrylic cutting process by laser cutting is very important, especially in low-powered lasers. The purpose of this research is to determine the appropriate parameters for cutting acrylic using a laser cutting machine with a power of 6.5 watts using the Taguchi method.

# 2. RESEARCH METHOD

This study uses the Taguchi method. The Taguchi method is a relatively new method in the engineering field which aims to improve the quality of products and its process. In its implementation, it does not require overall testing hence it can save time and research costs but still manage to produce good and accountable optimization values. (Irwan Soejanto, 2009).

The research process carried out can be described in a fishbone diagram as shown in the figure below.

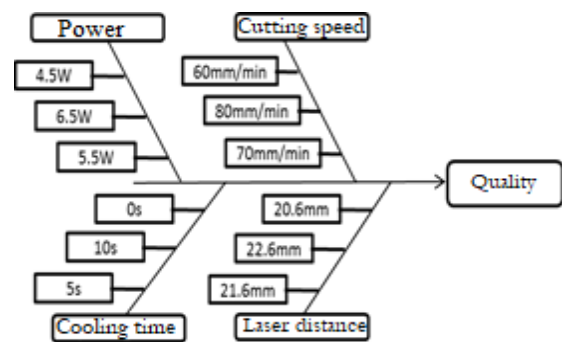


Figure 1. Fishbone Diagram Research

The data collection procedure follows an orthogonal matrix which can be seen in Figure 2. Figure 2 describes the data collection process that begins with cutting patterns making on acrylic and also G-codes making, followed by testing setting of tools and cutting tests,

then cutting is carried out according to the pattern that has been set. Afterward, the cutting is analyzed, if not appropriate, the tool needs to be redone. However, if appropriate, data collection will be operated. Data collection was done 27 times according to the orthogonal matrix. Furthermore, the cutting process is carried out by measuring the surface roughness using Surfcom SE300 and the measure of dimensional cutting results using a caliper. In this study the selected factors are laser power, cutting speed, cooling time, and laser distance. Experimental studies were conducted on a laser cutting machine with a module that has a maximum capacity of 6.5W with a workbench area of 271 x 191 mm.

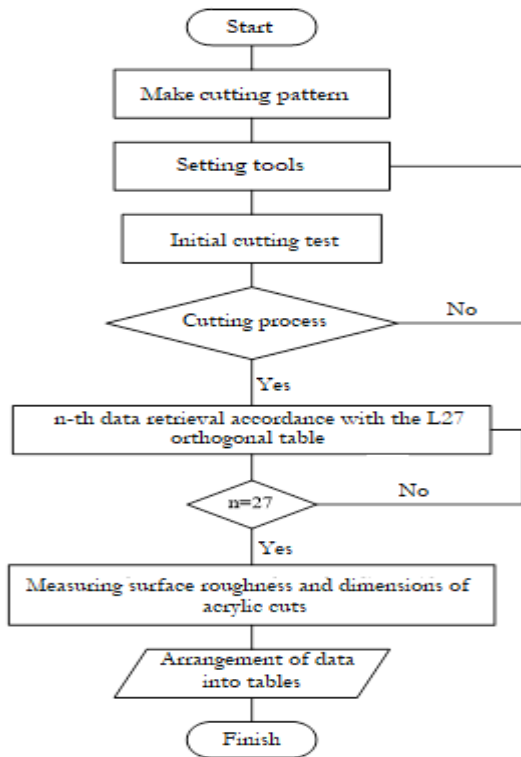


Figure 2. Data Collection Procedure

Planning begins with determining the factors that are included during the optimization process, then proceeds with the selection of the orthogonal matrix that has been defined in Taguchi's optimization theory.

In this study, the roughness value used as a guide is Ra. The JIS 0601 standard (surface roughness), specifies a workpiece length of 300% of the initial measured value. The set value is 0.08; 0.25; 0.8; 2.5; 8; 2.5 in mm (Sato

and Hartanto, 2005). In this case, a natural number of 2.5 mm is taken with the evaluation of three-length and the natural number of 7.5 mm.

### 3. RESULTS AND DISCUSSION

The data collection process follows the orthogonal matrix shown in table 2.

Table 2. Planned Data Collection Process

| Exp | Level                 |                                   |                      |                          |
|-----|-----------------------|-----------------------------------|----------------------|--------------------------|
|     | 1<br>Distance<br>(mm) | 2<br>Cutting<br>Speed<br>(mm/min) | 3<br>Power<br>(Watt) | 4<br>Cooling<br>(second) |
| 1   | 22,6                  | 60                                | 4,5                  | 0                        |
| 2   | 22,6                  | 60                                | 5,5                  | 5                        |
| 3   | 22,6                  | 60                                | 6,5                  | 10                       |
| 4   | 22,6                  | 70                                | 4,5                  | 5                        |
| 5   | 22,6                  | 70                                | 5,5                  | 10                       |
| 6   | 22,6                  | 70                                | 6,5                  | 0                        |
| 7   | 22,6                  | 80                                | 4,5                  | 10                       |
| 8   | 22,6                  | 80                                | 5,5                  | 0                        |
| 9   | 22,6                  | 80                                | 6,5                  | 5                        |
| 10  | 21,6                  | 60                                | 4,5                  | 5                        |
| 11  | 21,6                  | 60                                | 5,5                  | 10                       |
| 12  | 21,6                  | 60                                | 6,5                  | 0                        |
| 13  | 21,6                  | 70                                | 4,5                  | 10                       |
| 14  | 21,6                  | 70                                | 5,5                  | 0                        |
| 15  | 21,6                  | 70                                | 6,5                  | 5                        |
| 16  | 21,6                  | 80                                | 4,5                  | 0                        |
| 17  | 21,6                  | 80                                | 5,5                  | 5                        |
| 18  | 21,6                  | 80                                | 6,5                  | 10                       |
| 19  | 20,6                  | 60                                | 4,5                  | 10                       |
| 20  | 20,6                  | 60                                | 5,5                  | 0                        |
| 21  | 20,6                  | 60                                | 6,5                  | 5                        |
| 22  | 20,6                  | 70                                | 4,5                  | 0                        |
| 23  | 20,6                  | 70                                | 5,5                  | 5                        |
| 24  | 20,6                  | 70                                | 6,5                  | 10                       |
| 25  | 20,6                  | 80                                | 4,5                  | 5                        |
| 26  | 20,6                  | 80                                | 5,5                  | 10                       |
| 27  | 20,6                  | 80                                | 6,5                  | 0                        |

After data collection is done in the form of cutting acrylic using laser cutting, the measure of the dimensional measurement results is carried out to see whether the calibration rehavets has haven sufficient, the results are shown in tabTable

Table 3. Cutting Result Dimension

| 1<br>Distance<br>(mm) | 2<br>Cutting<br>Speed<br>(mm/min) | 3<br>Power<br>(Watt) | 4<br>Cooling<br>(Second) | Dimension |
|-----------------------|-----------------------------------|----------------------|--------------------------|-----------|
| 22,6                  | 60                                | 4,5                  | 0                        | 2,465     |
| 22,6                  | 60                                | 5,5                  | 5                        | 2,5       |
| 22,6                  | 60                                | 6,5                  | 10                       | 2,49      |
| 22,6                  | 70                                | 4,5                  | 5                        | 2,5       |
| 22,6                  | 70                                | 5,5                  | 10                       | 2,5       |
| 22,6                  | 70                                | 6,5                  | 0                        | 2,5       |

|      |    |     |    |       |
|------|----|-----|----|-------|
| 22,6 | 80 | 4,5 | 10 | 2,47  |
| 22,6 | 80 | 5,5 | 0  | 2,5   |
| 22,6 | 80 | 6,5 | 5  | 2,48  |
| 21,6 | 60 | 4,5 | 5  | 2,47  |
| 21,6 | 60 | 5,5 | 10 | 2,5   |
| 21,6 | 60 | 6,5 | 0  | 2,49  |
| 21,6 | 70 | 4,5 | 10 | 2,475 |
| 21,6 | 70 | 5,5 | 0  | 2,5   |
| 21,6 | 70 | 6,5 | 5  | 2,465 |
| 21,6 | 80 | 4,5 | 0  | 2,495 |
| 21,6 | 80 | 5,5 | 5  | 2,5   |
| 21,6 | 80 | 6,5 | 10 | 2,47  |
| 20,6 | 60 | 4,5 | 10 | 2,5   |
| 20,6 | 60 | 5,5 | 0  | 2,5   |
| 20,6 | 60 | 6,5 | 5  | 2,46  |
| 20,6 | 70 | 4,5 | 0  | 2,5   |
| 20,6 | 70 | 5,5 | 5  | 2,49  |
| 20,6 | 70 | 6,5 | 10 | 2,49  |
| 20,6 | 80 | 4,5 | 5  | 2,5   |
| 20,6 | 80 | 5,5 | 10 | 2,47  |
| 20,6 | 80 | 6,5 | 0  | 2,475 |

According to table 3, the dimensions of the cutting results of each workpiece done by a caliper, there is shown the smallest measurement of 2,460 cm with a difference of 0.040 cm from the desired result, which is 2,500 cm, and the cutting results do not exceed 2,500 cm. The calibration was operated twice, before calibration, the cutting results had an accuracy of  $\pm > 5$  mm and after the first calibration the accuracy became  $\pm 1$  mm while in the second calibration the accuracy became  $\pm 0.040$  cm ( $\pm 0.40$  mm). The average measurement of the cutting results is 2,487 cm or 24.87 mm.

The results of surface roughness measurements using the Surfcomer SE300 are shown in table 4.

| Table 4.<br>Surface Roughness Measurement Results |                              |                 |                     |                    |       |
|---------------------------------------------------|------------------------------|-----------------|---------------------|--------------------|-------|
| 1                                                 | 2                            | 3               | 4                   | Surface            |       |
| Distance<br>(mm)                                  | Cutting<br>Speed<br>(mm/min) | Power<br>(Watt) | Cooling<br>(second) | Roughness<br>Value |       |
|                                                   |                              |                 |                     | Rep1               | Rep2  |
| 22,6                                              | 60                           | 4,5             | 0                   | 2,337              | 2,302 |
| 22,6                                              | 60                           | 5,5             | 5                   | 2,871              | 2,874 |
| 22,6                                              | 60                           | 6,5             | 10                  | 2,384              | 1,763 |
| 22,6                                              | 70                           | 4,5             | 5                   | 2,11               | 2,114 |
| 22,6                                              | 70                           | 5,5             | 10                  | 2,058              | 2,108 |
| 22,6                                              | 70                           | 6,5             | 0                   | 2,058              | 3,141 |
| 22,6                                              | 80                           | 4,5             | 10                  | 2,318              | 3,796 |
| 22,6                                              | 80                           | 5,5             | 0                   | 1,822              | 2,401 |
| 22,6                                              | 80                           | 6,5             | 5                   | 1,558              | 1,115 |
| 21,6                                              | 60                           | 4,5             | 5                   | 1,562              | 4,575 |
| 21,6                                              | 60                           | 5,5             | 10                  | 2,209              | 2,407 |
| 21,6                                              | 60                           | 6,5             | 0                   | 3,24               | 3,167 |
| 21,6                                              | 70                           | 4,5             | 10                  | 1,837              | 4,187 |
| 21,6                                              | 70                           | 5,5             | 0                   | 1,981              | 2,556 |
| 21,6                                              | 70                           | 6,5             | 5                   | 2,157              | 1,158 |
| 21,6                                              | 80                           | 4,5             | 0                   | 1,244              | 2,072 |
| 21,6                                              | 80                           | 5,5             | 5                   | 2,207              | 0,803 |

|      |    |     |    |       |       |
|------|----|-----|----|-------|-------|
| 21,6 | 80 | 6,5 | 10 | 3,418 | 1,55  |
| 20,6 | 60 | 4,5 | 10 | 1,592 | 2,062 |
| 20,6 | 60 | 5,5 | 0  | 1,952 | 2,212 |
| 20,6 | 60 | 6,5 | 5  | 0,782 | 1,881 |
| 20,6 | 70 | 4,5 | 0  | 2,046 | 1,751 |
| 20,6 | 70 | 5,5 | 5  | 2,558 | 1,702 |
| 20,6 | 70 | 6,5 | 10 | 1,259 | 1,311 |
| 20,6 | 80 | 4,5 | 5  | 2,56  | 2,999 |
| 20,6 | 80 | 5,5 | 10 | 1,681 | 1,59  |
| 20,6 | 80 | 6,5 | 0  | 3,631 | 2,373 |

The S/N ratio in this study is required to be closer to zero to show the betresultssult, then the formula for the S/N ratio is as follows:
$$N = \log_{10}\left(\frac{1}{n} \sum_{i=1}^r Y_i^2\right)$$

The results of the calculation of the S/N ratio can be seen in table 5. For the calculation of the S/N ratio, only the final average value of the surface roughness is calculated and if each experiment is calculated, there will be 27 calculations.

| Table 5. S/N Ratio Calculation Results |                           |                 |                     |        |
|----------------------------------------|---------------------------|-----------------|---------------------|--------|
| 1                                      | 2                         | 3               | 4                   | S/N    |
| Distance<br>(mm)                       | Cutting Speed<br>(mm/min) | Power<br>(Watt) | Cooling<br>(second) |        |
| 22,6                                   | 60                        | 4,5             | 0                   | 7,308  |
| 22,6                                   | 60                        | 5,5             | 5                   | 9,165  |
| 22,6                                   | 60                        | 6,5             | 10                  | 6,430  |
| 22,6                                   | 70                        | 4,5             | 5                   | 6,494  |
| 22,6                                   | 70                        | 5,5             | 10                  | 6,480  |
| 22,6                                   | 70                        | 6,5             | 0                   | 8,482  |
| 22,6                                   | 80                        | 4,5             | 10                  | 9,953  |
| 22,6                                   | 80                        | 5,5             | 0                   | 6,573  |
| 22,6                                   | 80                        | 6,5             | 5                   | 2,637  |
| 21,6                                   | 60                        | 4,5             | 5                   | 10,676 |
| 21,6                                   | 60                        | 5,5             | 10                  | 7,273  |
| 21,6                                   | 60                        | 6,5             | 0                   | 10,113 |
| 21,6                                   | 70                        | 4,5             | 10                  | 10,192 |
| 21,6                                   | 70                        | 5,5             | 0                   | 7,184  |
| 21,6                                   | 70                        | 6,5             | 5                   | 4,767  |
| 21,6                                   | 80                        | 4,5             | 0                   | 4,654  |
| 21,6                                   | 80                        | 5,5             | 5                   | 4,406  |
| 21,6                                   | 80                        | 6,5             | 10                  | 8,477  |
| 20,6                                   | 60                        | 4,5             | 10                  | 5,306  |
| 20,6                                   | 60                        | 5,5             | 0                   | 6,387  |
| 20,6                                   | 60                        | 6,5             | 5                   | 3,170  |
| 20,6                                   | 70                        | 4,5             | 0                   | 5,594  |
| 20,6                                   | 70                        | 5,5             | 5                   | 6,739  |
| 20,6                                   | 70                        | 6,5             | 10                  | 2,180  |
| 20,6                                   | 80                        | 4,5             | 5                   | 8,906  |
| 20,6                                   | 80                        | 5,5             | 10                  | 4,276  |
| 20,6                                   | 80                        | 6,5             | 0                   | 9,735  |

After the S/N ratio is determined, the total square calculation is carried out with the following formula:

$$S_a = \frac{A_1^2}{n_{A1}} + \frac{A_2^2}{n_{A2}} + \frac{A_3^2}{n_{A3}} - \frac{T^2}{N}$$

$$MS_A = \frac{SS_A}{VA}$$

$$SS_T = \sum \bar{Y}^2$$

$$S_m = n \times \bar{y}^2$$

$$SS_{faktor} = SS_A + SS_B + SS_c + SS_D$$

After the total square calculation is done, the percentage of each factor tested can be found. The formula for finding the percentage factor is as follows:

$$\rho = \frac{SS'}{SS_T} \times 100\%$$

The percentage of each factor can be seen in table 6.

Table 6. The influence of each factor

| No | Factor         | Influence Percentage |
|----|----------------|----------------------|
| 1  | Cutting Speed  | 40,90%               |
| 2  | Laser Distance | 25,40%               |
| 3  | Laser Power    | 18,90%               |
| 4  | Cooling Time   | 7,05%                |

The graph of the influence factors on surface roughness is shown in Figure 3, Figure 4, Figure 5, and Figure 6.

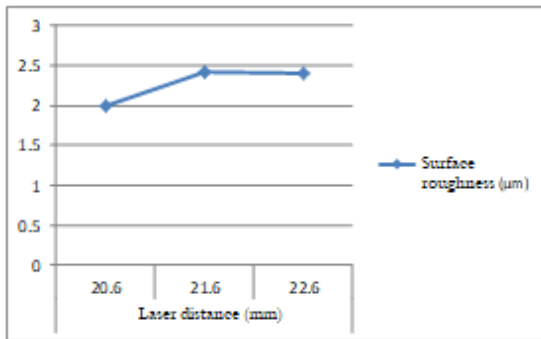


Figure 3. Graph of Laser Distance Factor on Surface Roughness

Figure 3 shows that, at a distance of 20.6 mm, the lowest average surface roughness is produced, and the highest average of surface roughness has produced the distance of 21.6.

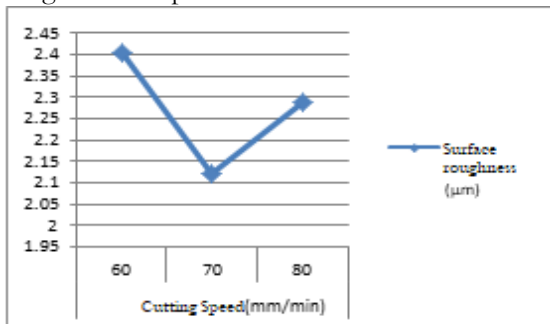


Figure 4. Graph of the Effect of Cutting Speed on Surface Roughness

Based on Figure shows that there is a significant difference at each level of cutting speed. A cutting speed of 70 mm/min resulted in the lowest average surface roughness, and a cutting speed of 60 mm/min resulted in the highest surface roughness.

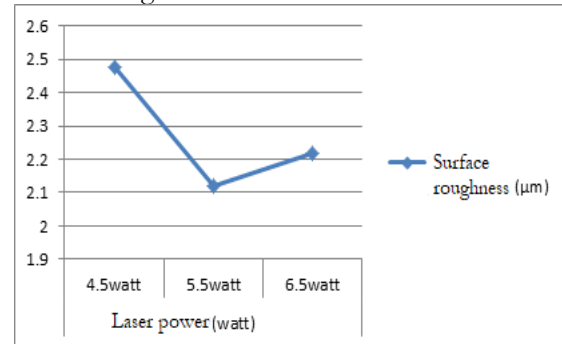


Figure 5. Graph of the Effect of Laser Power on Surface Roughness

Based on Figure 5, there is shown the effect of laser power on the surface roughness of acrylic cutting, for 4.5 watts of power there produced the highest average surface roughness, and 5.5 watts of power produces the lowest average surfaces roughness. While the laser power of 6.5 watts produces an average roughness value of 2.22 μm.

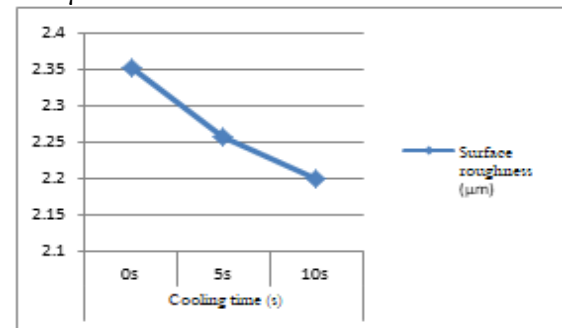


Figure 6. Graph of Effect of Cooling Time on Surface Roughness

Based on Figure 6, showsshowss the effect of cooling time on the surface roughness of acrylic cutting, the graph shows that 0s cooling time or no cooling time shows the highest surface roughness value. The average value of surface roughness decreases along with the increase of cooling time.

## 4. CONCLUSION

Based on this experiment, the best cutting result with the lowest average roughness value and the dimensional cutting results above the average is the laser distance factor of 20.6 mm, cutting speed of 70mm/min, laser power of 6.5 watts, and the cooling time of 10 seconds. Meanwhile, the best overall roughness value was obtained d with a laser distance factor of 20.6 mm, cutting speed of 70 mm/min, laser power of 5.5 watts, and a cooling time of 10 seconds.

The percentage of influence of each factor in laser cutting is 27% for laser distance, 40.9% for cutting speed, 18.9% for laser power, and 7.05% for cooling time. According to the percentage obtained in the cutting speed factor, it is known that if the laser movement is too slow then the cutting results will not be optimal because it is causing the acrylic to be overloaded on one side which made the cutting surface not well or even failed. The same thing applies to other factors.

After calibrating the software, the accuracy of the cutting results increased by 60% from the initial accuracy value, namely from  $\pm 1\text{mm}$  to  $\pm 0.4\text{ mm}$ . Also, after the calibration, the cutting results were relatively consistent with the desired results of 25 mm on each side and no cutting results exceeded the planned value of 25 mm.

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