OPERATION MANUAL

# BenchO In a nut shell

Started by

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BenchO project group

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**Abstract**

BenchO is an open source project started by BetterPrint3r.Inc. Aiming to provide a universal test standard for the field. In the test, we provide specialised models and procedure to estimate the capability of your 3D printer. The test now is for consumer grade FDM printer only. The project is entirely open source. Suggestions and comments are always welcomed.

# Contents

# 1 Preparation for a standard test

## 1.1 Print models

**General Info**

In the following section we will specify the parameters for standard test. You should print 6 parts in total to perform a complete test.

In our official test, all data are collected with standard PLA+ filament from eSUN.This type of filament should be widely available and easy to purchase. If you use other types of filament. The result will be less comparable and will not be accept for official ranking.

This standard is created for desktop FDM 3D printers. Using this on other types of printer will generate inconclusive results.

**About Slicing software**

All models should strictly follow the designated parameters in a standard test. You should start with a default profile in your slicing software and then change the parameters specified in the following section. For the parameters undeclared in the following section, keep it default.

Turn on all possible settings in your slicer. If you cannot find the settings required. Then it must be hidden in some advance menu in your slicing software.

Do not rotate the model along Z Axis in your slicing software

If you found severe issue with build plate adhesion, you can add brim. But we recommend you not to do so.

**Basic precision**

There is only one model in this section. *Basic.stl*

Using any default profile will be sufficient. You do not have to modify anything in specific but you could try different layer height.

**Engineering**

There are two models: *Engineering1.stl* and *Engineering2.stl*

Table 1: Engineering1.stl

| Setting | Parameter |
|---|---|
| Layer height | 0.2mm |
| Wall line count | 2 |
| Infill density | 100% |
| Infill pattern | line |
| Support | None |

Table 2: Engineering2.stl

| Setting | Parameter |
|---|---|
| Layer height | 0.2mm |
| Wall line count | 2 |
| Infill density | 66% |
| Infill pattern | Triangles |
| Top layers | 0 |
| Bottom layers | 0 |
| Support | None |

**Art**

There are two models: *Art1.stl* and *Art2.stl*

Table 3: Art1.stl

| Setting | Parameter |
|---|---|
| Layer height | 0.2mm |
| Wall line count | 3 |
| Infill density | 0% |
| Top layers | 0 |
| Support | None |

Table 4: Art2.stl

| Setting | Parameter |
|---|---|
| Layer height | 0.2mm |
| Wall line count | 2 |
| Infill density | 20% |
| Support | None |

**Ruler**

There are one model:*Ruler.stl*

Table 5: Ruler.stl

| Setting | Parameter |
|---|---|
| Layer height | 0.2mm |
| Wall line count | 2 |
| Infill density | 20% |
| Support | None |

Ruler Placement

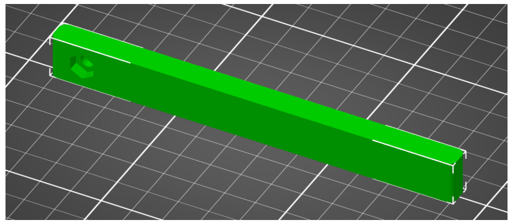

Figure 1: When printing this part you should put the ruler along one of the axis

## 1.2 Tools

A caliper with resolution not less than 0.01mm and range larger than 100mm will be sufficient for the measurement. All data should be taken in metric system.

The printed ruler in previous section will be your additional tool.

Check your ruler with known straight edge.

# 2 Take measurement

## 2.1 Basic precision

During measurement you should ignore the defects that are easy to remove. The test is designed to reflect the capability of your printer.

Large Scale

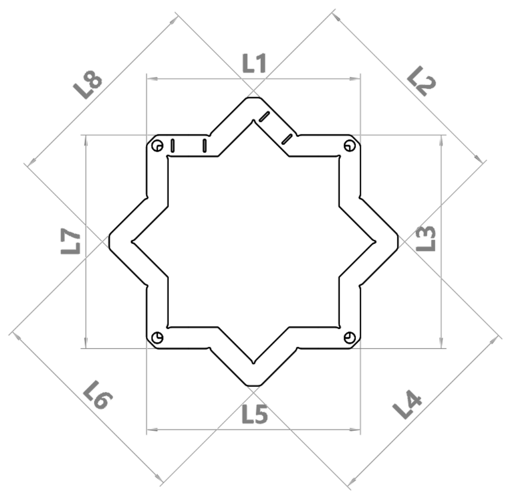


Figure 2: This is the top view of the test model.You should take 8 measurements and fill the associative blank.

Small Scale

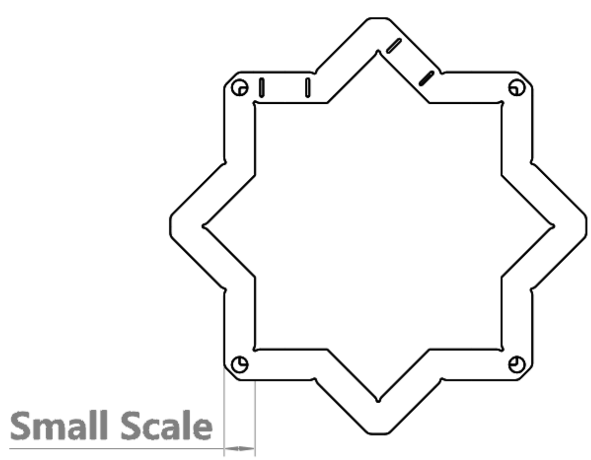


Figure 3: This is the top view of the test model.You should take 10 measurements and fill the associative blank.In this part you do not have to take data by order.

Z Axis

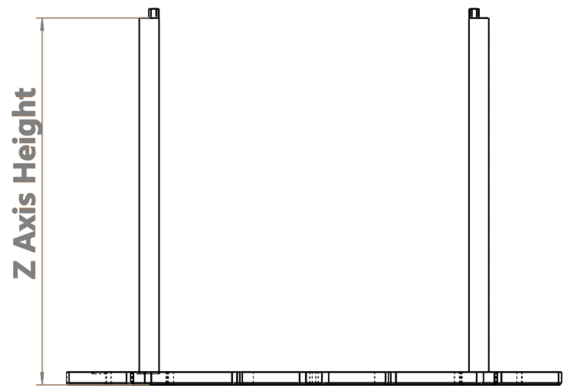


Figure 4: This is the front view of the test model.You should take 4 measurements and fill the associative blank.In this part you do not have to take data by order.

## 2.2 Engineering

**Surface flatness and parallel**

Horizontal thickness

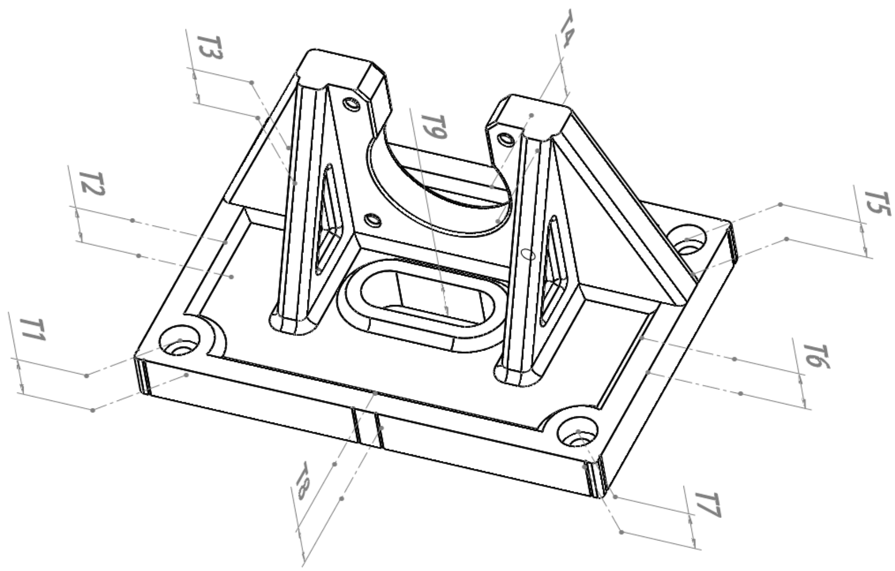


Figure 5: You should take 8 measurements and fill the associative blank.

Vertical thickness

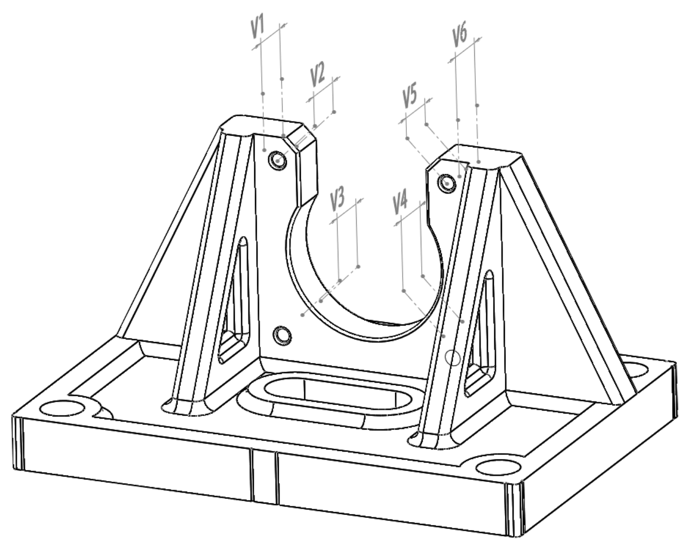


Figure 6: You should take 6 measurements and fill the associative blank.

## Curvature

You should first bolt or fix your ruler in one of the four corner and then measure the gap between your ruler and the opposite side of the base. If there is no gap at all. Your result will be 0mm.

Curvature X Axis

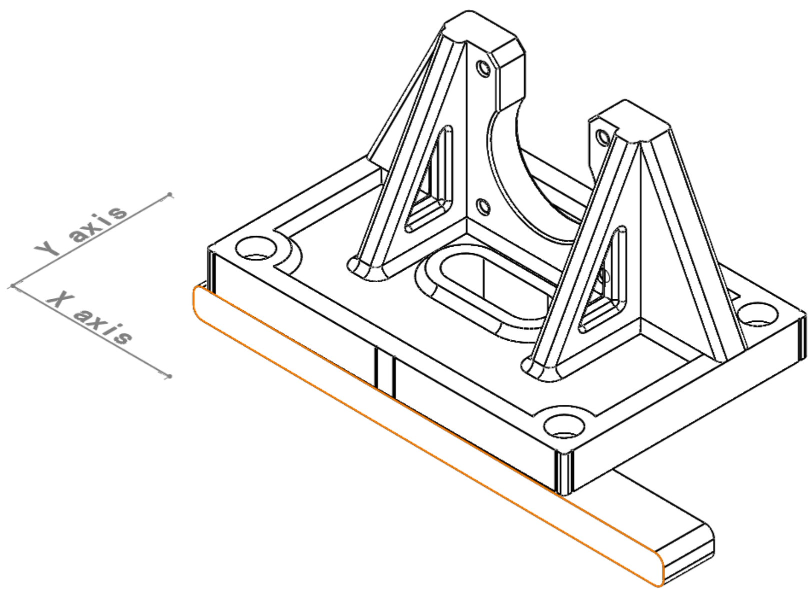


Figure 7: This will be an example for X axis measure

Curvature Y Axis

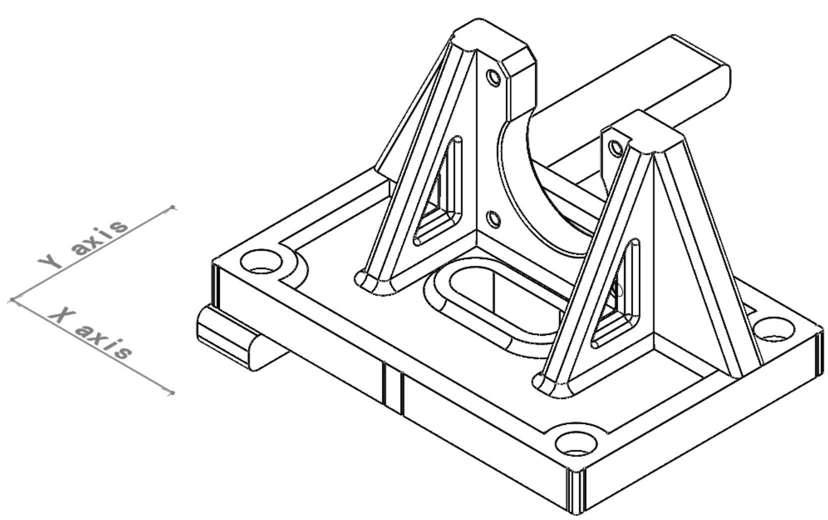


Figure 8: This will be an example for Y axis measure

**Shafts and holes**

Shafts and holes

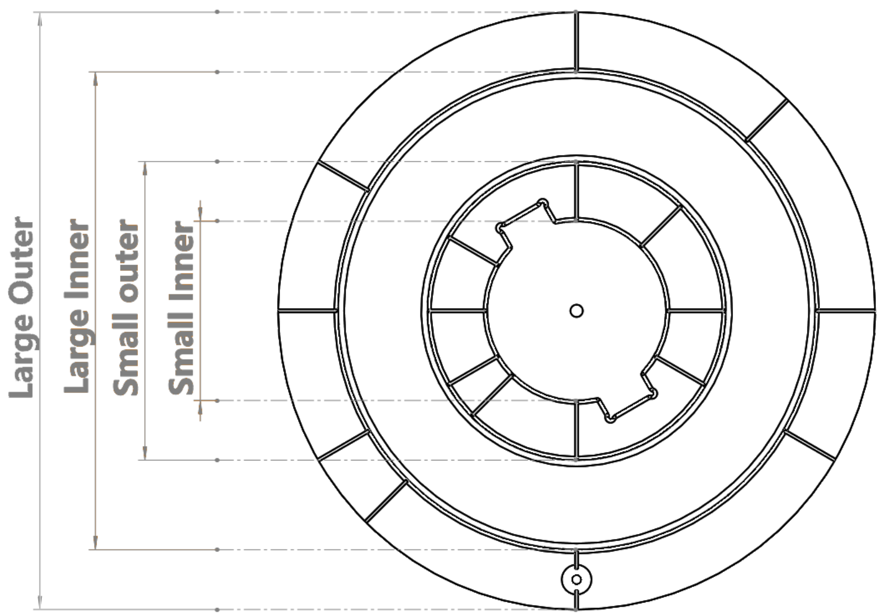


Figure 9: This is the Top view of the test model.You should take 6 measurements for each dimension and fill the associative blank.

## 2.3 Art

Bridge

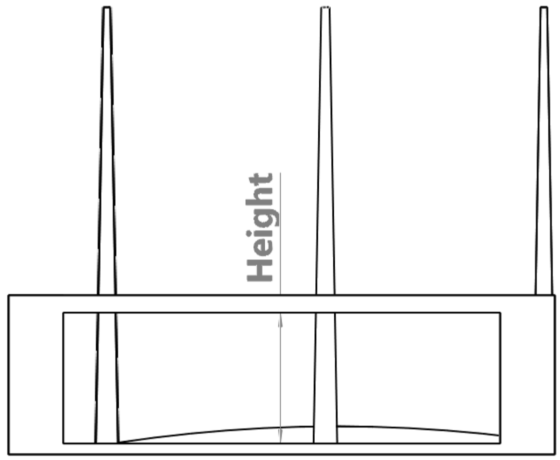


Figure 10: This is the front view of the test model.You should measure the minimum distance between the bridge and base. Assess the degree of stringing between spikes.

Overhang

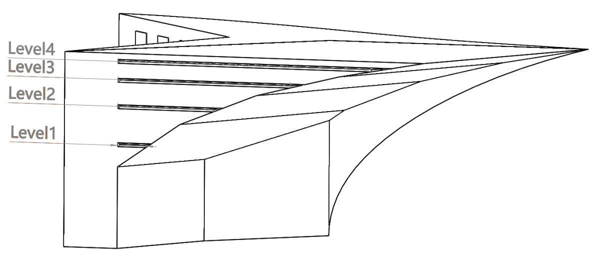


Figure 11: Check if there are major defects. Record the number of level that is perfectly printed.

Cameo and Ringing

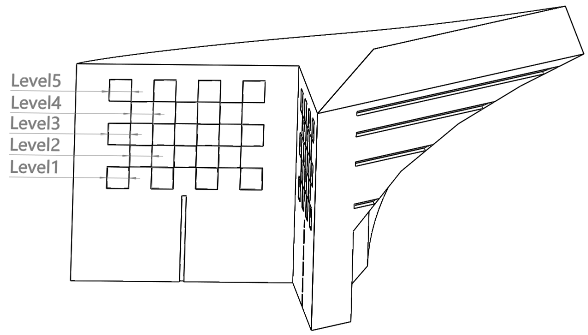


Figure 12: Record the number of cameo level that is well printed.

# 3 Result Data analysis

## 3.1 Basic precision

The aim of this part is to characterise the basic properties of your printer. The difference between designed and printed is called *accuracy*. And the distribution (relative difference from average) is called *precision*.

For all accuracy assessment we applied ISO 286. We took the maximum difference from the designed and see which tolerance grade it fits in. The maximum score for accuracy is 4.See Appendix for more detailed information.

For precision measurement we use a classic natural log function:

$$Score = 6e^{-\sigma} \tag{1}$$

Where $\sigma$ is the standard deviation calculated from collected data. With formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x-\bar{x}_i)^2}{N-1}} \tag{2}$$

Where N is the total number of data collected.

## 3.2 Engineering

This part refers to model *Engineering1.stl*. The model is actually an nema 17 step motor base. By printing this 100 % infill part we would evaluate the capability of your printer to produce engineering part that needs to be solid and accurate.

**Section1:Flatness and Parallel**

There are 9 measurement for thickness (T1-T9). Where the last one is the middle point thickness.

The degree of Parallel is determined by the difference of averages values between opposite side. The divergence in this section reflects the angle between your upper edge direction and your lower edge ones.

For example, in figure 5 the X direction divergence will be calculated by:

$$Div = Sin^{-}1(\frac{T1+T2+T3}{T5+T6+T7}) \tag{3}$$

The base surface is marked as uneven if either the standard deviation of the thickness is larger than 0.5 or the maximum difference between data is larger than 0.4. If the surface is Uneven then the flatness score will be halved:

$$\begin{gathered} if\ Uneven\ A = 0.5 \\ else\ A = 1 \end{gathered} \tag{4}$$

The other part of flatness will be measured by the standard deviation $\sigma_T$ for all thickness point:

$$Score = Ae^{-\sigma_T} \tag{5}$$

These two values are multiplied to produce the final flatness score.

**Section1:Vertical distortion**

In this section we measure the degree of overshooting due to motor movement. If the machine cannot properly accelerate and decelerate then it will leave a relative large difference between point

V1,V6 and the rest.

The score it calculated by fitting the maximum distortion in to our tolerance table.

**Section2:Curvature**

This section shows the curvature and bending of your printed base part (which is the base of $Engineering1.stl$). The radius in this section calculated by using the bottom base edge as the arc of a circle. For an ideal plane the radius should be infinite.

The approximate radius is calculated by:

$$r = \frac{L}{2sin(tan^{-1}(\frac{d}{L}))} \tag{6}$$

Where L is the length of the base and d is the mean bending distance you obtained.And the score is then calculated by:

$$score = 1 - e^{-\frac{r}{10^3.5}} \tag{7}$$

**Section3:Shafts and Holes**

In this section the ability to print holes and shafts are tested. For each dimension (Large inner,Large outer, etc) two main features are valued. First is the relative precision of the holes or shafts printed. The difference of extremes are fitted in to H/h grades in ISO 286-2 chart. The difference between actual printed holes/shafts and designed ones is compared with ISO 286 Chart. Which will be valued the same as it is in basic precision. Additionally, if a hole is undersized or a shaft is oversized. The deduction of marks will be doubled. This is because in real life an oversized shaft and a undersized hole will be really painful to fit.

## 3.3 Art

In art we evaluate the ability of your printer to produce artistic products.

A printer with good score in stringing and ringing test will do better in producing good surface detail.

Cameo level, disk feature and spikes tells you how well your printer is in making fine details and small structures.

The overhang and bridge test shows the cooling ability of your print head.

A printer score high in art section will likely to produce art with fewer defects.

# 4 Acknowledgement

## 4.1 License

# 5 Appendix

## 5.1 Tolerance Table (ISO 286)

Tolorence table

| Grade | 100mm(mm) | 10mm(mm) | 30mm(mm) | 50mm(mm) | 80mm(mm) | Score |
|---|---|---|---|---|---|---|
| Perfect | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.00 |
| IT8 | 0.054 | 0.022 | 0.033 | 0.039 | 0.046 | 1.00 |
| IT9 | 0.087 | 0.036 | 0.052 | 0.062 | 0.074 | 0.90 |
| IT10 | 0.140 | 0.058 | 0.084 | 0.100 | 0.120 | 0.80 |
| IT11 | 0.220 | 0.090 | 0.130 | 0.160 | 0.190 | 0.70 |
| IT12 | 0.350 | 0.150 | 0.210 | 0.250 | 0.300 | 0.60 |
| IT13 | 0.540 | 0.220 | 0.330 | 0.390 | 0.460 | 0.50 |
| IT14 | 0.870 | 0.360 | 0.520 | 0.620 | 0.740 | 0.40 |
| IT15 | 1.400 | 0.580 | 0.840 | 1.000 | 1.200 | 0.30 |
| IT16 | 2.200 | 0.900 | 1.300 | 1.600 | 1.900 | 0.10 |
| Reject | 3.000 | 3.000 | 3.000 | 3.000 | 3.000 | 0.00 |

## 5.2 Shafts and Holes (ISO 286-2)

| Shafts | | | | |
|---|---|---|---|---|
| Grade | (30mm,50mm] | (50mm,80mm] | (80mm,120mm] | Score |
| Perfect | 0.000 | 0.000 | 0.000 | 1.00 |
| 5 | 0.011 | 0.001 | 0.015 | 1.00 |
| 6 | 0.016 | 0.019 | 0.022 | 0.90 |
| 7 | 0.025 | 0.030 | 0.035 | 0.80 |
| 8 | 0.039 | 0.046 | 0.054 | 0.70 |
| 9 | 0.062 | 0.074 | 0.087 | 0.60 |
| 10 | 0.100 | 0.120 | 0.140 | 0.50 |
| 11 | 0.160 | 0.190 | 0.220 | 0.30 |
| 12 | 0.250 | 0.300 | 0.350 | 0.10 |
| Reject | 1.000 | 1.000 | 1.000 | 0.00 |

| Holes | | | | | |
|---|---|---|---|---|---|
| Grade | <=30 | <=50 | <=80 | <=120 | Score |
| Perfect | 0.000 | 0.000 | 0.000 | 0.000 | 1.00 |
| 6 | 0.013 | 0.016 | 0.019 | 0.022 | 1.00 |
| 7 | 0.021 | 0.025 | 0.030 | 0.035 | 0.90 |
| 8 | 0.033 | 0.039 | 0.046 | 0.054 | 0.8 |
| 9 | 0.052 | 0.062 | 0.074 | 0.087 | 0.6 |
| 10 | 0.084 | 0.1 | 0.12 | 0.14 | 0.4 |
| 11 | 0.13 | 0.16 | 0.19 | 0.22 | 0.2 |
| Reject | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 |

## 5.3 Art

| Cameo level | |
|---|---|
| level | Score |
| 0 | 0.00 |
| 1 | 0.20 |
| 2 | 0.40 |
| 3 | 0.60 |
| 4 | 0.80 |
| 5 | 1.00 |

| Stringing level | |
|---|---|
| Condition | Score |
| Clean | 1.00 |
| Ok | 0.60 |
| Bad | 0.20 |
| Fail | 0.00 |

| Spikes | |
|---|---|
| Height | Score |
| Full | 1.00 |
| Most | 0.70 |
| Some | 0.50 |
| Nope | 0.00 |

| Disk | |
|---|---|
| Height | Score |
| 0.025mm | 1.00 |
| 0.05mm | 0.70 |
| 0.1mm | 0.50 |
| Fail | 0.00 |

| Overhang | |
|---|---|
| Height | Score |
| 4 | 1.00 |
| 3 | 0.75 |
| 2 | 0.50 |
| 1 | 0.25 |
| 0 | 0.00 |

| Ringing level | |
|---|---|
| Condition | Score |
| 2mm | 1.00 |
| 4mm | 0.70 |
| 8mm | 0.50 |
| Fail | 0.00 |

## 5.4 Score Weight

| section | subsection | Weight | Subtotal |
|---|---|---|---|
| Part1: Basic Precision | XY relative precision | 6 | 18 |
| | XY accuracy | 4 | |
| | Small Scale accuracy | 4 | |
| | Z axis accuracy | 4 | |
| Part2: Engineering | Base Quality | 10 | 25 |
| | Edge and corner | 5 | |
| | Large Holes | 2.5 | |
| | Large Shafts | 2.5 | |
| | Small Holes | 2.5 | |
| | Small Shafts | 2.5 | |
| Part3: Art | Overhang Level | 4 | 25 |
| | cameo level | 4 | |
| | Ringing size(Included) | 5 | |
| | Clear space between bridge | 1 | |
| | Bridge to bottom Distance(mm) | 3 | |
| | Stringing | 3 | |
| | Full height | 1 | |
| | Disk(Minimum layer height) | 4 | |
| Part4:Time | Engineering1 | 10 | 32 |
| | Engineering2 | 6 | |
| | Art1 | 10 | |
| | Art2 | 6 | |
| Total | | | 100 |