Experimental Research and Mechanical Analysis of Levelling Parametric Characterization of 3D Printer

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Abstract. Based on the Delta 3D printer this paper carries out levelling experimental research and explores the changes of position parameter of the moving parts when the hot bed is in the horizontal and inclined states. It also conducts a comparative analysis to find a method for parametrically characterizing the levelling states of the 3D printer, and grasps the attitude characteristics of the nozzle in different levelling states. At the same time, the paper also carries out a mechanical analysis to explore the effect of the blowing direction of the fan and the inclination of the hot bed on print quality under different levelling states.

1. Introduction
Levelling is an important step in 3D printing. The levelling state greatly affects the print quality and machine life. Existing fused deposition 3D printers rarely have an accurate levelling system and usually rely on the operator's feeling and experience to determine the levelling state of the machine. This method is not accurate enough and the printed parts cannot meet the requirements of industrial applications. Therefore, in order to explore the parametric characterization of precise levelling, the paper carries out experimental research based on the Delta3D printer and comparatively analyses the positional parameters of the moving parts of the printer under different levelling states. The paper also carries out mechanics analysis under different levelling states to explore and demonstrate the effect of the levelling states on print quality.

2. Experimental Apparatus
The experiment uses a Delta3D printer, also known as a parallel arm 3D printer, using the fused deposition printing principle. The three sets of parallel arms are connected to the nozzle components and the column sliders by ball hinges, as shown in Figure 1. The printer has 3 columns and 3 sliders. The three sliders on the columns are driven by the motor to move up and down linearly when printing, so as to realize the movement of the three parallel arms. The parallel arms drive the nozzle to print according to the cross-sectional profile and scanning path of the workpiece.
3. Levelling Experiment

The levelling of the 3D printer is an important step in 3D printing. The levelling state has a great influence on the print quality and the machine life. When the 3D printer is levelling, the friction between the A4 paper and the hot bed is used to determine the gap between the nozzle and the hot bed. And then the friction determines the levelling state of the printer. This kind of operation is very inaccurate. It depends entirely on the operator's feeling and experience, and cannot be visually displayed with specific numbers. Therefore, in order to explore the quantitative characterization method of the levelling states, the paper carries out levelling mechanism analysis and experimental research.

The printed layers are formed directly on the hot bed and the attitude of the hot bed directly affects the growth of the printed layers. Therefore, the levelling state of the printer can be reflected by the attitude of the hot bed. By carrying out the printing experiments with the hot bed in horizontal and inclined states, the height $h$ of the upper surface of the slider and the surface of the hot bed, the angle $\gamma$ between the three parallel arms and the columns are measured, as shown in Figure 1. In the experiment, the inclined state is achieved by raising the C-column 1cm. The corresponding $h$ and $\gamma$ on the three columns (numbered a, b, and c) are respectively denoted as $h_1$, $h_2$, $h_3$, and $\gamma_1$, $\gamma_2$, $\gamma_3$. The measured values are shown in Table 1.
Table 1. Measured values of $h$ and $\gamma$ in two levelling states (height unit: cm)

| state of the hot bed | number of the column | $\gamma_1$ | $h_1$ | $\gamma_2$ | $h_2$ | $\gamma_3$ | $h_3$ |
|----------------------|----------------------|------------|-------|------------|-------|------------|-------|
|                      | a                    | 6°         | 12.6  | 36°        | 9.3   | 38°        | 9.3   |
| horizontal state     | b                    | 32°        | 9.3   | 6°         | 12.6  | 38°        | 9.3   |
|                      | c                    | 34°        | 9.3   | 36°        | 9.3   | 6°         | 12.6  |
|                      | a                    | 8°         | 12.6  | 39°        | 9.3   | 32°        | 9.3   |
| inclined state       | b                    | 37°        | 9.3   | 7°         | 12.6  | 37°        | 9.3   |
|                      | c                    | 35°        | 9.3   | 37°        | 9.3   | 5°         | 12.6  |

Through the comparative analysis of the data in Table 1, we can see:

1) When the hot bed is inclined, the three $h$ values remain unchanged and only the three angle $\gamma$ values change. It shows that when levelling is in different states, the distance of the three sliders is the same and the three groups of parallel arms can achieve different attitudes of the nozzle by adjusting the angle with the column. Therefore, the levelling state of the printer can be characterized according to the change of the angle $\gamma$.

2) When printing the same layer, the slider runs at the same distance, and its speed and acceleration are only a function of the angle $\gamma$.

3) If there is height error due to shrinkage or the levelling effect is not good, the printer can adjust itself by adjusting the three angles $\gamma_1$, $\gamma_2$, and $\gamma_3$.

4) After the c-column is raised, there is a certain inclination between the hot bed and the horizontal plane. It is found in the experiment that the attitude of the nozzle and the hot bed keeps perpendicular. In other words, the printed layers are printed in a direction perpendicular to the hot bed. The center of gravity of the printed layers is inclined, and the gravity $G$ of the printed layers has a component $G_1$ perpendicular to the normal direction, which will cause additional bending effect, as shown in Figure 2. At the same time, because the printing material has a certain fluidity when it is fused, the tilt of the center of gravity will also cause the slip between layers. The boundary of the printed layers and normal direction will generate a certain angle $\beta$, which will make the step effect more obviously and the surface quality of the workpiece will decline.
5) The cooling fan is fixed on the nozzle part. After the c-column is raised, the blowing angle of the fan remains unchanged, but the blowing range increases. This will affect the cooling uniformity of the printed layers, as shown in Figure 3.

4. Mechanical Analysis
In order to deeply investigate the influence of the blowing direction and the tilt of the hot bed on the printed layers, the mechanical analysis of the blowing direction is carried out by comparing the horizontal and inclined states of the hot bed. The cooling fan of the printer is fixed and the fan speed is not adjustable. Therefore, the force of the fan blowing on the workpiece can be regarded as a uniformly distributed load. Set the load intensity is \( q \), the angle between the blowing direction and the horizontal orientation is \( \theta \), the inclined angle of the hot bed is \( \alpha \). The mechanical analysis model is shown in Figure 4.

It can be seen from Figure 4 that when the hot bed is in a horizontal state, the distributed load \( q \) can be decomposed into \( q_1 \) and \( q_2 \).

\[
q_1 = q \cos \theta \quad (1)
\]
\[
q_2 = q \sin \theta \quad (2)
\]

When the hot bed is in an inclined state, the distributed load \( q \) can be decomposed into \( q_3 \) and \( q_4 \).

\[
q_3 = q \cos(\theta - \alpha) \quad (3)
\]
\[
q_4 = q \sin(\theta - \alpha) \quad (4)
\]

It can be seen from the expressions of \( q_1 \sim q_4 \) that:
1) The blowing of the fan will have a certain bending effect and compression effect on the printed layers.

2) When the hot bed is inclined, the components of the distributed load (q3, q4) are completely different from (q1, q2) in the horizontal state and related to the inclined angle (α) of hot bed.

3) The blowing angle θ is a constant, and the inclined angle α of the hot bed varies with the levelling quality and is an uncertain quantity. It can be seen from the expressions of q3 and q4 that the change of α has no effect on q3. The change of α has a greater influence on q4, which may cause the direction of q4 to reverse, and the force effect on the printed layers will change accordingly. The details are shown in Equation 5.

\[
\begin{align*}
q_3 &> 0, \quad q_4 > 0 & \alpha &< \theta \\
q_3 & = q, \quad q_4 = 0 & \alpha &= \theta \\
q_3 & > 0, \quad q_4 < 0 & \alpha &> \theta
\end{align*}
\]

5. Conclusion

On the basis of carrying out the levelling experiment of 3D printer, this paper compares the changes of the position parameters of the printer under two levelling states (the hot bed is horizontal and inclined), and finds the parameters that can characterize the levelling states of the printer. At the same time, the paper analyses the position parameters, grasps the attitude characteristics of the nozzle in different levelling states, and finds out the influence factors on the print quality when the hot bed is inclined. Finally, a mechanical analysis is carried out by constructing the mechanical analysis model. The effects of the blowing direction and the inclination of the hot bed on the print quality under different levelling states are discussed.

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