Modification Simulation Research on Handle Speed of Faucet Test System

Bin Li, Jingyuan Xu, Jie Chen*, Jianguo Sun
School of Mechatronic Engineering and Automation, Shanghai University, Shanghai 200444, PR China
jane.chen@shu.edu.cn

Abstract. In order to improve the accuracy and the repeatability of the faucet sensitivity test in the faucet test equipment, this paper proposes an improved scheme for adding a camera system into the rotation control device. This paper first explains the working principle of the rotation control device, then establishes and analyzes the motion model of the motor driven faucet handle rotation, and then proposes a motor speed compensation scheme based on the image processing result according to the model. The accuracy of the faucet handle speed under the compensation scheme is obviously improved.

1. Introduction
Ceramic cartridge faucets are common parts of kitchen and bathroom hardware products and are closely related to life, the internal quality of faucet products is mainly reflected in the regulation performance of the outlet water temperature and flow rate[1]. Faucet test system, as the main test equipment for product development and product quality control, can provide technical support for the rapid development of the faucet industry[2][3], and play a certain role in the specification and development of faucet products. GB 18145-2014 "Ceramic Cartridge Faucets"[4] sensitivity requirements specifies the speed of the handle operating device should be adjusted to 0.5°/s during a sensitivity determination[5]. The traditional faucet test system has a large error in the measurement of the faucet stroke angle, so that the actual handle speed is quite different from the 0.5°/s specified by the standard, which eventually leads the faucet sensitivity test record to be less informative. In order to overcome the above shortcomings, the camera system is added to the rotation control device of the current test system for improvement in this paper. Simulation experiments and actual tests show that the improved scheme proposed in this paper improves the detection accuracy and repeatability of faucets.

2. Rotation control device
2.1. Working principle
The rotation control device is mainly composed of a servo motor and a fixture for rotating the faucet handle. The motor is located at the uppermost position of the device with a fixed horizontal mounting position, where the fixture is connect to the motor axis. The position of the camera is located directly below the motor with a constant relative height to the motor, ensuring that the center of the image is aligned with the motor axis in the horizontal direction. The horizontal position of the faucet can be adjusted before testing, and the motor, fixture and camera can be adjusted in height to achieve a suitable control position. The installation position of the motor, the camera and the faucet is shown in figure 1.
To complete a sensitivity test, the faucet needs to be mounted on the test platform, adjusting the height and position of the servo motor and the fixture so that the faucet handle can be controlled. The faucet stroke angle of the motor and the image are respectively obtained firstly, then the handle of the measured faucet is driven by the fixture to complete the test after the actual motor speed is calculated.

2.2. Establishment and analysis of motion model

When the motor axis drives the fixture to rotate, the faucet handle is rotated by the toggle. If the motor axis and the faucet rotation center are in the same position under ideal conditions, then the angle measured by the motor is the faucet stroke angle, and the handle speed will also be consistent with the motor speed. When the rotation center of the faucet does not coincide with the motor axis, the angle measured by the motor is not equal to the faucet stroke angle, and the rotation angle and the rotation speed of the handle and the fixture are inconsistent.

The requirement of the faucet handle rotation speed of the device is 0.5°/s. In order to determine the influence of the relative position between the faucet rotation center and the motor axis on the handle rotation speed, it is first necessary to simplify the model of the handle rotation, as shown in figure 2.

Figure 2. Handle rotation simplified model

\( O \) is the faucet rotation center, \( O_1 \) is the motor axis, \( A \) is the initial contact point between the motor fixture and the handle, and \( A_1 \) is the contact point of the fixture and the handle when the handle is completely rotated to the other end. \( A_2 \) is the contact point at a certain position during the rotation. A plane rectangular coordinate system is established with the faucet rotation center as the coordinate origin and the symmetry axis of the faucet as the \( y \)-axis in figure 2.

\( \theta \) is the faucet stroke angle, \( \theta_M \) is the motor measurement angle calculated by the motor encoder, and the handle speed is required as \( v_0 \) in the standard. Therefore, \( t_0 = \theta / v_0 \) is the rotation time of the
single stroke when faucets are tested. Since the mechanical connection between the motor fixture and the faucet handle is used, the motor rotates the angle of the handle to $\theta$ in $t_0$, so the average motor speed $\bar{v}_M$ is shown in equation (1).

$$\bar{v}_M = \frac{v_0 \theta_M}{t_0}$$  \hspace{1cm} (1)

In this device, $\theta$ is obtained by image processing by the camera. If the motor rotates at the constant speed of $\bar{v}_M$ obtained by equation (1), although the rotation time and the rotation angle are guaranteed, it may cause the non-uniformity of the actual rotational speed $v'_0$ of the handle, then $v'_0$ will likely exceed the required fluctuation range of 0.5°/s.

The following analysis of the effect of $O_1$ and $A$ on the actual speed $v'_0$ of the handle when the motor is rotating by the constant speed $\bar{v}_M$. Set $O_1(x, y)$, $O_1A = L_1$, $\angle AOA_1 = \theta$, assuming that $A_2$ is the contact point of the handle and the fixture at $t$. Then, according to the plane geometry knowledge, coordinate of $A$, coordinate of $A_1$ and the angle $\theta_1$ of $O_1A$ are obtained, so $\theta_2(t)$ of $O_1A_2$ at $t$ is as follows.

$$\theta_2(t) = \int \bar{v}_M \, dt + \theta_1$$  \hspace{1cm} (2)

Coordinate of $A_2$ at $t$ is defined as:

$$(x_{A_2}(t), y_{A_2}(t)) = (L_1 \cos \theta_2(t) + x, L_1 \sin \theta_2(t) + y)$$  \hspace{1cm} (3)

At $t$ The handle has been rotated by $\theta'(t)$:

$$\theta'(t) = \arctan \frac{y_{A_2}(t)}{x_{A_2}(t)}$$  \hspace{1cm} (4)

Therefore, the actual handle speed at $t$ is expressed as $v'_0(t)$:

$$v'_0(t) = \frac{d\theta'(t)}{dt}$$  \hspace{1cm} (5)

Take $L_1=6$, $\theta=110^\circ$, the movement speed of all the moments of the handle can be determined, when coordinate of $O_1$ are determined. At $O_1(1, -1), (2, -1), (1, 1), (0, -1)$ the parameters are substituted respectively into the above formulas, using Matlab to calculate the handle speed $v'_0(t)$, and obtaining the speed-time curve shown in figure 3.

![Figure 3. Handle speed at constant speed of the motor at different positions](image-url)
The four curves in figure 3 are the speed curves calculated by $O_4$ at (1, -1), (2, -1), (1, 1), (0, -1). As shown in the above figure, the horizontal offset of $O_4$ and $O$ is the main factor affecting the fluctuation of $v'_o$, and the larger the horizontal offset, the greater the fluctuation of $v'_o$. The closer the center of the two is to the fluctuation of the handle speed, the smaller the fluctuation.

3. Improvement of device

3.1. Camera system

As can be seen from the above analysis, the ideal position of the faucet should be mounted directly below the motor axis to ensure consistency between the faucet handle speed and the motor speed. Due to the mechanical installation method, the rotation center of the faucet is difficult to align with the motor axis, the rotation speed of the faucet handle will deviate from the rotation speed specified by the standard.

Under the condition that the center of the image has been concentric with the motor axis, when the faucet rotation center is adjusted to the center of the image from the image, the centers of the three coincide, realizing the operation of centering with the camera as a bridge.

After the position of the faucet, motor and fixture is adjusted, the step of calculating the faucet stroke angle can be entered. The visual inspection system of this paper adopts CMOS industrial camera[6] to image the faucet to be measured, and the acquired image is digitized and input into the computer for angle inspection. The method of visual inspection has better accuracy, and it can be considered that the result of the image method measurement is the actual faucet stroke angle, and the result will be used to correct the motor speed.

3.2. Handle speed correction

In this paper, a ten-segmentation compensation scheme based on image measurement results is adopted for the motor speed. When the motor rotates at constant speed $v_M$, if the actual speed of the handle $v'_o$ is too large, which reduces the motor speed at this time. Correspondingly, the motor speed at this time is increased by $v'_o$ during the stroke. It is guaranteed that the average motor speed $\bar{v}_M$ and the total motor travel $\theta_M$ will not change.

Since the eccentricity of the installation faucet is almost unavoidable, and the faucet is symmetrical in the manner of symmetrical installation, the rotation speed of the motor is also relatively flat during the speed compensation, and the motor control method of the speed compensation for the two strokes is identical.

In this device, only the faucet stroke angle $\theta$ and the motor measurement angle $\theta_M$ can be obtained, and the motor axis and the faucet rotation center cannot obtain an accurate position. Therefore, considering $\Delta \theta(\theta - \theta_M)$ as the reference of the compensation value $p$:

$$p = K \cdot \Delta \theta$$  \hspace{1cm} (6)

In the above equation (6), $K$ is used as a scale factor to adjust $p$. Considering that the stroke angle of a typical nozzle is about 100°, a 10-stage segmentation scheme is selected. In equation (7), $p$ is the motor speed compensation value, $t$ is the rotation time required for the handle speed to meet 0.5°/s, $\bar{v}_M$ is the average motor speed in $t$.

$$v_M = \begin{cases} v_M(1 + 2p) & [0, 0.1t), [0.9t, t] \\ v_M(1 + p) & [0.1t, 0.2t), [0.8t, 0.9t] \\ v_M & [0.2t, 0.3t), [0.7t, 0.8t] \\ v_M(1 - p) & [0.3t, 0.5t), [0.6t, 0.7t] \\ v_M(1 - 2p) & [0.4t, 0.6t] \end{cases}$$  \hspace{1cm} (7)

According to the compensation scheme, the corrected motor speed is substituted into the model established above. When the motor maintains constant speed before compensation, the handle speed has a certain fluctuation range, and the speed increases first and then decreases; after the compensation, the handle speed fluctuates when the motor shifts. The range is smaller, the speed is a dynamically changing curve, and the rotational speed is closer to 0.5°/s over the entire stroke.
The compensated handle speed is obtained by Matlab simulation, and the variance of the speed is compared with that before compensation. It can be seen from table 1 that the variance of the handle speed is reduced by about 10 times. It can be seen that the fluctuation degree of the handle rotation speed can be reduced by the speed compensation, and the stability is improved.

Table 1. Comparison of variance before and after motor speed compensation

| Faucet installation location \( (L_1=6\text{cm}, \theta=110^\circ) \) | Variance of handle speed before compensation | Variance of handle speed after compensation |
|---------------------------------------------------------------|---------------------------------------------|--------------------------------------------|
| \( O_1(0, -1) \)                                            | \( 1.48 \times 10^{-4} \)                     | \( 1.75 \times 10^{-5} \)                   |
| \( O_1(0, -2) \)                                            | \( 7.70 \times 10^{-4} \)                     | \( 8.37 \times 10^{-5} \)                   |

4. Conclusion
This paper proposes a faucet angle measurement and handle speed correction scheme based on image processing. The simulation experiment and the actual operation prove that the method of this study is feasible, which effectively improve the measurement accuracy of the faucet angle, and can better meet the test requirements of the standard. Therefore, the research in this paper is used in the faucet test equipment to improve the detection accuracy of the sample detection and expand the applicable range of the sample to be tested.

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