Research on Error and Compensation of Volume Measurement System for Nondestructive Testing

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Abstract. In order to improve the measurement accuracy of the three-dimensional non-destructive testing device for slice volume, the experimental error caused by the hydraulic loss of the experimental container is analyzed and compensated. Through the analysis of the overflow characteristics, the weir flow model of the overflow is established, the profile curve of the overflow and the overflow round tube are optimized to reduce local losses, and verified by experiment. The results show that the measurement accuracy of the liquid volume is improved by about 54.85%, and this optimization scheme is effective. By optimizing the experimental device, the error is compensated to ensure the accuracy of data collection.

1. Introduction

For the measurement of mechanical parts containing internal contours, there is no ideal measurement method at home and abroad\(^1\)\(^-\)\(^3\) to measure and reconstruct it. The proposed three-dimensional non-destructive measurement method based on the volume measurement of grid slices realizes the measurement of all water-insoluble materials with complex shapes with internal contours of through holes\(^4\), which has the advantages of fast measurement speed and high accuracy. Figure 1 is the measurement device. The key technology is: using the layering principle to achieve layered displacement through precision motion feed, complete the slice volume measurement in different directions, and establish a three-dimensional coordinate mathematical model of the slice microgrid. And then, process and solve measured data by using intelligent algorithms. Finally, a three-dimensional reconstruction method based on ordered point clouds is proposed to realize the recognition of internal contours and the restoration of solids. This device is the core of obtaining slice volume data. In this system, it is found that the volatility of the liquid has an impact on its accuracy, and there is liquid loss during the flow of the liquid from the overflow, which includes the liquid caused by the shape of the overflow and the surface wettability Errors, and local losses in the overflow tube. Therefore, this article takes this measurement device as the research object, abstracts the container overflow as a practical weir model, and analyzes the overflow characteristics to optimize the overflow profile curve to reduce local losses. Through experimental verification, the experimental device The error is compensated and its effectiveness is verified.
Figure 1. A Schematic Diagram of A Lamellar Volume Measurement Device

2. Experimental device error analysis

2.1 Liquid volatility analysis

In order to observe the effect of liquid volatilization on errors, the design experiment is as follows:

Place the balance on a horizontal surface, turn it on and preheat it, connect it to the computer; set the room temperature to 20℃ through the air conditioner and 50% humidity through the humidifier. Take a few static liquids at room temperature, place them in a liquid dish, and place the liquid dish in a precision balance; start the computer to start recording data, and record for 2 hours under the above conditions. By analyzing the intercepted experimental data, as shown in Figure 2.

According to the image analysis, it is not difficult to find that the liquid evaporation amount y and the time x satisfy the relationship of (1):

\[ y = -0.0212x + 80.16 \]  

After calculation, at normal temperature, the liquid volatilization rate is 0.0212 mg / ℃. Over time, the liquid began to lighten under the influence of evaporation and volatilization, but in the end the liquid lightening rate slowed down. The reason for the analysis may be that as the liquid evaporated and volatilized, its liquid density became greater and greater, and the liquid appeared in a crystalline state.

2.2 Head loss analysis

The laboratory measuring container uses an acrylic plate. After calculation and experimental verification, the final design is a rectangular open design with a 5 mm circular opening and a tube angle of 30 °, as shown in Figure 3.

Figure 2. Evaporation rate of liquid  Figure 3. Volume measurement vessel diagram

For this measuring container, due to wettability, when the object begins to immerse in the liquid, the liquid is first adsorbed on the surface of the object, and the liquid level drops to a certain extent. As the immersion depth deepens, the liquid level begins to rise. When the liquid level rises to a certain height, it begins to overflow, and when the object stops immersing, the liquid does not stop overflowing in time. Therefore, when the liquid overflows, the actual sheet volume measurement value is reduced due to the influence of wettability.

In addition, the liquid flowing through the inner wall of the pipeline has two types of loss along the way and local loss, and the biggest impact is local loss.
2.2.1 Partial loss analysis. Normally, the liquid does not always flow straight in the round tube. When there is a change in the diameter or flow direction of a round tube or a valve (valve, water meter, etc.) is stored on the round tube, the liquid will also generate additional energy loss, which is a local loss. The reason for this is that after the liquid passes through the above-mentioned position, the flow velocity distribution of the cross-section will change drastically, forming a vortex-shaped reflux area behind these obstacles. According to the characteristics of the fluid, the vortices in these return areas will continuously convert the kinetic energy into the inner wall of the heat transfer pipe and dissipate it in the form of heat. Thereby reducing the mechanical energy of the liquid. The loss formula is expressed as:

$$h_j = \xi \frac{v^2}{2g}$$  \hspace{1cm} (2)

In the formula: $\xi$ represents the local resistance coefficient.

The laminar flow error in the liquid circular tube can be added absolutely. In order to quantify the loss, design experiments to analyze, the experimental steps are as follows:

Block the water outlet of the round tube, put 10 cm³ standard parts in the container, and when the liquid level is stable, carry out the peeling and weighing operation;

Open the round tube and start counting. When all the liquid flows into the liquid dish, record the time and the quality of the liquid;

Repeat the above operation many times, and take the average value of each group of data as the final recording parameter.

The calculation formula of liquid velocity is:

$$v = \frac{l}{t} = \frac{\Delta m}{\rho \Delta l t}$$  \hspace{1cm} (3)

In the formula: $d$ represents the inner diameter of the round tube; $\rho$ represents the liquid density; $t$ represents the measurement time;

The calculated flow velocity is 0.03 m/s, and the liquid flow velocity is slow, which is related to the container design.

Then the Reynolds number is Re:

$$Re = \frac{vd}{\nu} = \frac{0.03 \times 5 \times 10^{-3}}{0.893 \times 10^{-6}} = 28$$  \hspace{1cm} (4)

In the formula: $v$ represents liquid flow rate; $d$ represents liquid density; $\nu$ represents dynamic viscosity coefficient (look-up table).

Therefore, according to the Reynolds coefficient, the liquid flow characteristic can be judged as laminar flow; then the Darcy coefficient is $80/Re$. In this experimental device, because the round tube is a thin straight round tube, there is no change in the interface flow, so the local loss is not considered for the time being. It can be calculated that when the liquid in the container flows through a 50 mm long round tube, the pressure $\Delta p$ needs to be lost:

$$\Delta p = \rho g (h_j + h_i)$$  
$$= 1.0 \times 10^3 \times 9.81 \times (\frac{64}{28} \times \frac{50}{2} \times \frac{0.03^2}{2 \times 10})$$  
$$= 10 Pa$$

The results show that the pressure of 10 Pa is lost. According to the principle of liquid transmission pressure, the liquid needs to rise by a certain height $\Delta h$ to overcome the lost pressure and reach the overflow condition:

$$\Delta h \geq \frac{\Delta p}{\rho g} = \frac{10}{1 \times 10^3 \times 9.81} = 1 mm$$  \hspace{1cm} (6)

The calculation results show that in its volume measurement system, due to the influence of the liquid surface tension and the wetting effect of the container, at the beginning of the measurement object entering the measurement liquid, in order to overcome its tension, the liquid will be lifted by at least about 1 mm, making the sheet feed At the beginning, there will be no liquid overflow.
3 Container optimization design and experimental verification

3.1 Container optimization design
In view of the hydraulic loss of the experimental container, the optimized design of the original container is considered.

In the experiment, when the measured object enters the liquid, the liquid changes from a static state to a flowing state. When the liquid surface is higher than the overflow, the liquid begins to flow out. This flow model can be regarded as a weir model in open channel flow in hydraulics[5]. The weir flow model is often used for flow measurement in the laboratory, which is in line with the purpose of this experiment.

According to the weir flow situation, the ratio of the weir flow top thickness $\delta$ to the weir flow head height $H$, the basic types of weir flow are: thin-walled weir, practical weir, wide crest weir. Under the action, a single descent curve is formed, which belongs to the practical weir model. In the weir flow, the discharge coefficient of the curve practical weir is the largest, and the WES profile design curve is usually adopted, and the discharge coefficient $m = 0.502$. As shown in Figure 4, $H_d$ in the figure is the design head, the curvature radius of the arc section of the profile $R_1 = 0.5H_d$, $R_2 = 0.2H_d$, $R_3 = 0.04H_d$; arc length $x_1 = 0.175H_d$, $x_2 = 0.276H_d$, $x_3 = 0.282H_d$.

With a design accuracy of 1 mm, according to the analysis of the error of the head loss in section 3.3, the height of the head is 1 mm; The WES profile curve parameters are as follows:

$$R_1 = 0.5\text{mm}, R_2 = 0.2\text{mm}, R_3 = 0.04\text{mm}, x_1 = 0.175\text{mm}, x_2 = 0.276\text{mm}, x_3 = 0.282\text{mm}.$$

The speed of a certain amount of liquid flowing down through the laminar flow can be regarded as the movement of a rigid body. The speed $v = v_0 + at$, where $a = g\sin\theta$, when $\theta$ is equal to $90^\circ$, that is, when the pipe is perpendicular to the horizontal plane, the liquid water velocity reaches the largest, the shortest measurement time.

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![Figure 4. WES Curve](image1)

![Figure 5. Improved design of overflow containers](image2)

The loss of the liquid along the way is mainly caused by the wetting effect between the liquid and the pipe. The better the wettability of the liquid and the round tube, the more residual liquid, which is unfavorable for the measurement data collection. This status quo can be changed by increasing the hydrophobicity of the inner wall of the round tube.

3.2 Measurement and compensation experiment verification
Design experiments and optimize verification:

The 9 sets of standard parts to be tested are placed in the measuring fixture to debug the level of the equipment; in order to eliminate the effect of positioning errors, it is planned to put the test parts into the liquid at a time, and after each feed is completed, the measurement data will be read regularly and smoothly; Repeat the above experiment 10 times and take the final average as the recording parameter. The experimental results are shown in Table 1.
Table 1. Optimized comparison of volume measurement systems

| Parallel block size(mm) | Before optimization | Optimized |
|-------------------------|---------------------|-----------|
|                         | Liquid quality(g)   | Liquid volume(ml) | Liquid quality(g) | Liquid volume(ml) |
| 8*14*150                | 12.2569             | 12.3857    | 14.5387           | 14.8354           |
| 8*16*150                | 14.8431             | 14.9990    | 16.9225           | 17.2678           |
| 8*20*150                | 19.7974             | 20.0054    | 21.5144           | 21.9534           |
| 8*24*150                | 24.3432             | 24.5990    | 26.1025           | 26.6352           |
| 8*30*150                | 31.9474             | 32.2831    | 33.2947           | 33.9741           |
| 8*32*150                | 34.3641             | 34.7252    | 35.8185           | 36.5494           |
| 8*36*150                | 38.9641             | 39.3735    | 40.6002           | 41.4287           |
| 8*40*150                | 43.8141             | 44.2745    | 45.2369           | 46.1601           |
| 8*44*150                | 48.7761             | 49.2880    | 49.8315           | 50.8484           |

The experiment proves that after the optimized design of the container, the measurement accuracy of the liquid volume is improved by about 54.85%.

The following will be verified by compensation of the slice accuracy through specific mechanical parts.

As shown in Figure 6, the experimental verification model is a boss with a base diameter of 100 mm, a height of 20 mm, and a draft angle of 3°. Place the parts on the table of the clamping device, and also verify the experiment with a feed of 1 mm.

The experimental environment is controlled at 20 degrees Celsius, and the experimental measurement device system is shown in Figure 7. A total of 10 slices were measured in the experiment, a total of 10 measurements were made, and the measurement results were averaged. Through the optimization of the volume measurement system, the results are shown in Figure 8:

4 Conclusion

In the volume measurement system, the factor that has the greatest influence on the volume measurement of the slice is the liquid overflow loss. Secondly, according to the characteristics of the hydraulic weir model, the profile curve of the container overflow port is optimized to reduce the liquid overflow and the loss along the way, thereby reducing the measurement error of the slice volume. The results show that the accuracy of the liquid volume measurement is improved by about 54.85%, and the error compensation of the experimental device is effective, which is helpful for the later part point cloud reconstruction.
Acknowledgments
Thanks my tutor for his guidance in this project, and my classmates for their help and encouragement in the experiment. This work is financially supported by National Nature Fund (51665008) Research on Nondestructive Measurement and reconstruction of mechanical parts based on grid slice volume measurement.

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