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A method for measuring the wall-thickness of thin-walled spherical shell parts

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Abstract

Spherical shell thin-wall parts are often used as experimental pieces of shock wave and detonation physics experiments. The experimental effect is analyzed by comparing the deformation and destruction of parts before and after the physical experiment. Therefore, the surface accuracy and wall-thickness uniformity of thin-wall spherical shell parts are relatively high requirements. The current method for obtaining wall-thickness of the component requires the help of a complicated wall-thickness measurement device, and operation is complicated. In order to obtain the wall-thickness of thin-wall spherical shell parts accurately, a wall-thickness measurement method is proposed. The meridian and the concentric trajectory are used to measure the wall-thickness of thin-wall spherical shell parts. The measurement benchmark coincides with the model; the measurement data of the inner and outer surfaces are unified in a same coordinate system, and wall-thickness error is obtained based on a reconstruction model method of spherical shell parts. The meridian and concentric circles are used to test a spherical shell with the outer diameter of Φ210.6 mm and the inner diameter of Φ206.4 mm. After removing the data points near the top, the surface error of the outer surface is about 5 µm, the surface error of the inner surface is about 6 µm, and the wall-thickness error is about 6 µm.

Keywords: Spherical shell; Thin-walled part; Wall-thickness; Benchmark coincidence; Data processing

1. Introduction

There are a large number of thin-walled parts in aerospace equipment, such as rocket tank panels, rocket nozzles and aircraft skins [1]. Spherical thin-walled parts have typical geometric shapes, and the mathematical description of deformation and failure is easy to express. In terms of physical design, spherical thin-walled parts have the typical advantages of "high energy efficiency and low energy consumption", which are also often used as shock wave physics and detonation physics. Spherical thin-walled parts as typical test pieces are used to study the essential mechanism of various physical, chemical and mechanical phenomena during weapon implosion [2]. The deformation and destruction of the parts before and after the experiment are used as the result to obtain the important parameters involved in the characterization of the weapon implosion process. In order to improve the accuracy and reliability of important scientific experimental data of shock wave physics and detonation physics, the surface shape accuracy and wall-thickness uniformity of thin-walled parts of spherical shell put forward extremely high requirements [2-3]. The characteristics of thin-walled parts, such as low rigidity, easy deformation, and difficult to clamp, are a major difficulty in the thickness measurement of thin-walled parts. For the wall-thickness measurement of curved parts, the difficulty is that the wall-thickness information of the part needs to be obtained in the normal direction of a certain point on the curved surface.

At present, researchers at home and abroad have explored the wall-thickness measurement. The methods of measuring wall-thickness mainly adopts direct measurement method and indirect measurement method. The main principle of the direct measurement method is to directly measure the distance between the inner and outer walls in the normal direction of the corresponding point as the point's wall-thickness. Cao et al. proposed a contact sensor measurement scheme. By constructing a theoretical curve, the articulation center is established to always move along the motion curve, so that the connection between the fixed contact and the sensor probe is always in the normal direction of the inner wall to obtain the wall-thickness value of workpiece [4]. Jin et al. proposed a tubing wall-thickness measurement method based on a measurement sensor and designed an online tubing wall-thickness measurement system with a wall-thickness measurement accuracy of ± 0.05 mm [5]. The indirect measurement method is mainly based on the principle of ultrasonic measurement, and the wall thickness information is calculated by the indirect quantity related to the wall thickness. Wu et al. used the principle of ultrasonic reflection to measure the thickness of the pipeline by calculating the difference in the arrival time of the echo signal according to the arrival time of the echo signal [6]. In order to reduce the influence of the measurement environment on ultrasonic measurement, Morana et al. used Monte Carlo simulation method to establish a mathematical model for the estimation of ultrasonic measurement thickness uncertainty [7]. The process of the direct method is cumbersome and the measurement takes a long time. Ultrasonic measurement is highly dependent on temperature and the ultrasonic system. The measurement environment and the strength of the ultrasonic echo signal have a greater impact on the measurement result, and the cost of the ultrasonic device is relatively high. For spherical shell parts with micron level precision, the above method is not suitable for the wall thickness detection of spherical shell parts.

This paper proposes a method for measuring the wall-thickness of thin-walled spherical shell parts. The measuring trajectory is planned for thin-walled spherical shell parts. By establishing a measurement reference coincidence model under the spatial coordinate system, the data on the inner and outer surfaces are unified to the same coordinate system. Based on the reconstruction model method of spherical shell parts, the wall thickness information is obtained.

2 Methodology

The thin-walled spherical shell parts, as shown in Figure 1, may be rotate and move along the x-axis, y-axis and z-axis, or rotate around its own axis with the angle φ, as shown in Figure 2, when measuring the inner and outer surfaces. Therefore, a new method for measuring the wall-thickness of thin-walled spherical shell parts is proposed. In the process of measuring the inner and outer surfaces of the spherical shell part, the flange circumference is used as measurement benchmark. By making the two flange circumferences coincide, the rotation angle and the amount of movement are obtained. The measurement benchmark coincidence model under the spatial coordinate system is established, and the data of the inner and outer surfaces are unified under the same coordinate system. Finally, the reconstruction model of the spherical shell parts is established through interpolation, and the wall-thickness is obtained. The measurement trajectory mainly includes the meridian and the concentric trajectory, as shown in Figure 3. The measurement process is shown in Figure 4.

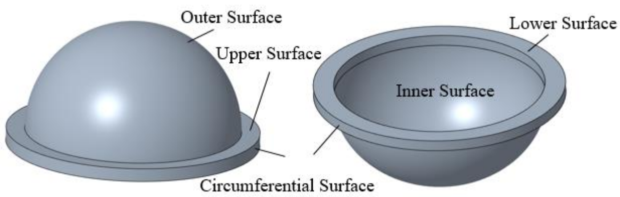
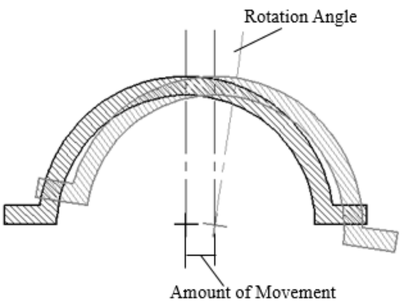
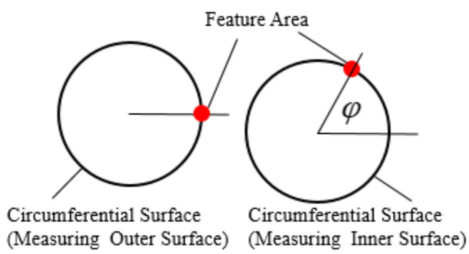


Figure.1 The spherical shell parts

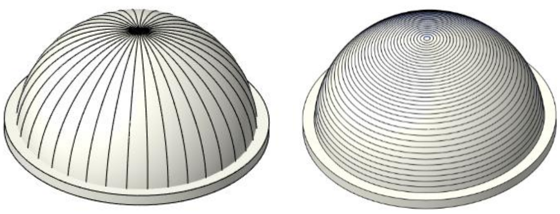


(a) The amount of rotation and movement



(b) The rotation angle

Figure.2 The Schematic



(a) The meridian trajectory (b) The concentric trajectory

Figure.3 The measurement trajectory

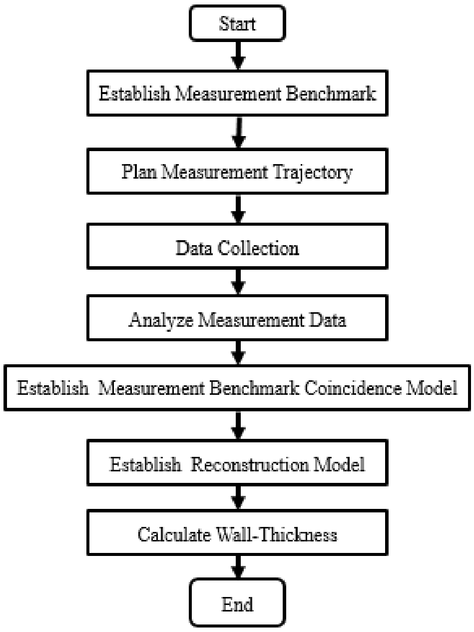


Figure.4 The measurement process

3. Experimental setups

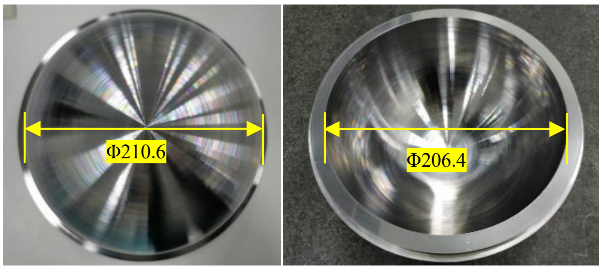
A spherical shell part with an outer diameter of Φ210.6 mm and an inner diameter of Φ206.4 mm is used for the measurement test, as shown in Figure 5. The processing machine adopts an ultraprecision single point diamond machine manufactured by Precitech, USA, which parameters are shown in Table 1. During the machining process, the pure iron spherical shell part is machined with cemented carbide tool (KC5010), and the constant speed is used for machining. The specific parameters are shown in Table 2.

Table 1 The machine parameters

Parameter Type	Parameter Value
X Stroke (mm)	350
Z Stroke (mm)	300
Position Feedback Accuracy (nm)	0.032
X Horizontal Straightness (μm/ 25mm)	0.05
Z Horizontal Straightness (μm/ 25mm)	0.05
Spindle Load (kg)	85
Spindle Radial Runout (nm)	≤15
Spindle Axial Runout (nm)	≤15
Maximum Spindle Speed (rpm)	7000

Table 2 The related parameters in processing

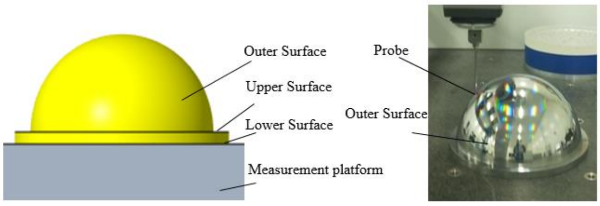
Parameter Type	Parameter Value
Tool Radius (mm)	0.2
Spindle Speed (rpm)	200
F (mm/min)	20
ap (μm)	10
Adsorption Pressure (kPa)	50



(a) The outer surface (b) The inner surface

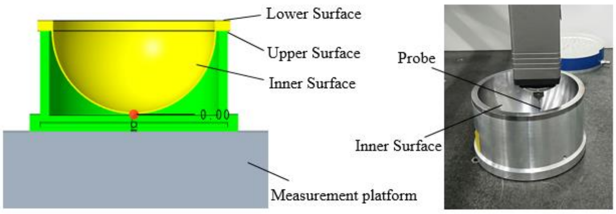
Figure.5 The processed spherical shell

Taking the lower face of flange as the measurement benchmark. First, measuring the circumferential surface of flange according to the circular track, and measuring the outer surface according to the meridian and concentric circles, as shown in Figure 6. After that, the lower face of flange is used as the measurement benchmark again, and the circumferential surface of flange is measured again according to the circular trajectory of the last time, and the inner surface is measured according to the meridian and concentric trajectory, as shown in Figure 7.



(a) The measurement model (b) Measuring the real object

Figure.6 The outer surface measurement



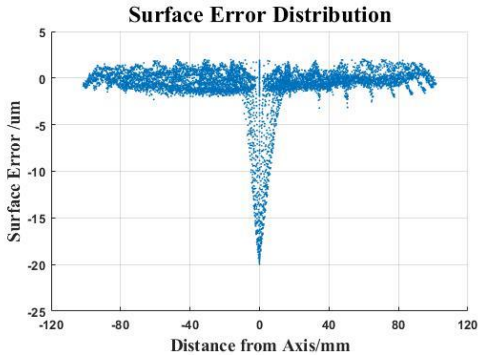
(a) The measurement model (b) Measuring the real object

Figure.7 The inner surface measurement

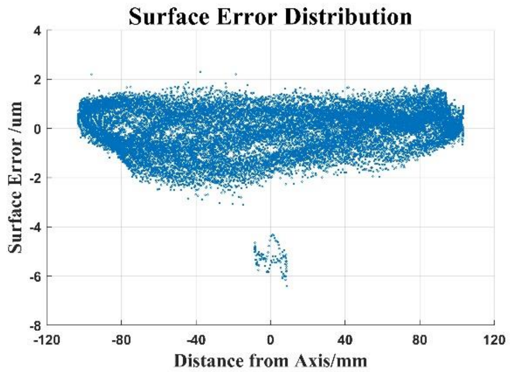
4. Results and discussion

4.1 Surface accuracy

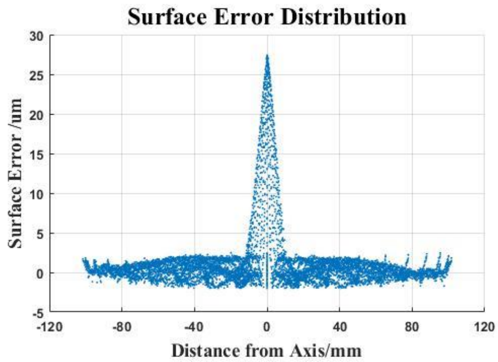
Using the meridian trajectory measurement method, the surface error of the outer surface of the spherical shell part near the top is about 22 μm, and the surface error after removing the data points near the top is about 5 μm, and the surface error of the inner surface of the spherical shell near the top is about 27 μm, and the surface error after removing the data points near the top is about 6 μm. When measuring with concentric circles, the surface error of the outer surface of the spherical shell near the top is about 8 μm, and the surface error after removing the data points near the top is about 5 μm; the surface error of the inner surface near the top is about 14 μm, and the surface error after removing the data points near the dome is about 8 μm, as shown in Figure 8.



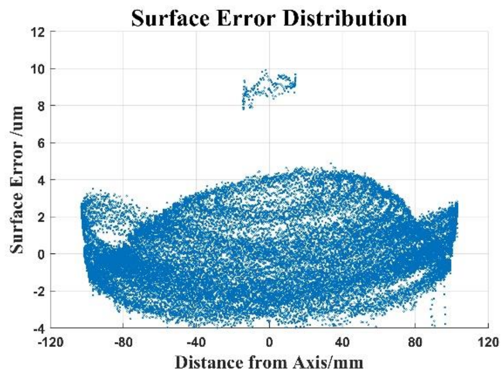
(a) Surface error distribution of the outer surface with the meridian trajectory



(b) Surface error distribution of the outer surface with the concentric trajectory



(c) Surface error distribution of the inner surface with the meridian trajectory

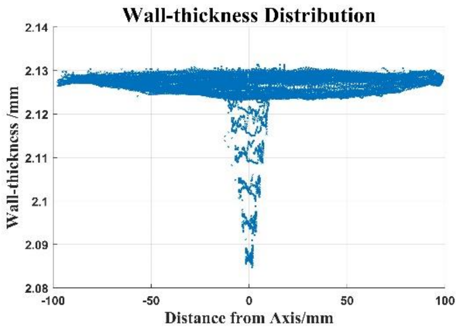


(d) Surface error distribution of the inner surface with the concentric trajectory

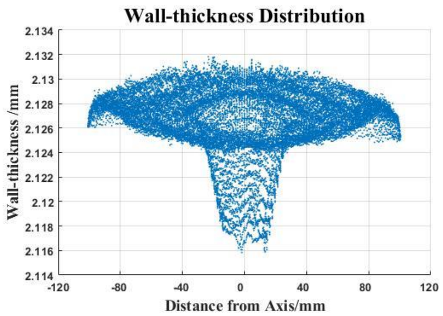
Figure. 8 The surface error distribution

4.2 Wall-thickness

Drawing the spherical shell wall-thickness distribution in polar coordinates, as shown in Figure 9. The wall-thickness error of the spherical shell part with meridian trajectory is about 45 μm. The wall-thickness error of the spherical shell part with concentric trajectory is about 16 μm. After removing the data near the top, the wall-thickness error is about 6 μm with the meridian trajectory, and the wall-thickness error is about 7 μm with the meridian trajectory.



(a) The wall-thickness distribution with the meridian trajectory



(b) The wall-thickness distribution with the concentric trajectory)
Figure.9 The wall-thickness distribution

4.3 Discussion

The surface error of the top using the meridian trajectory is larger than that of the concentric trajectory. This is because the measurement of the concentric circle method fails to collect the top data information. In actual processing, due to the poor cutting conditions at the top, the presence of entangled chips and a long distance from the positioning surface (flange) will result in a large wall-thickness error, making the uniformity of the wall-thickness at the top more difficult guarantee. The meridian trajectory can more accurately reflect the wall-thickness information at the top, so for the measurement of spherical shell parts, the meridian trajectory is better than the concentric trajectory. Except for the top, the closer to the top, the greater the wall-thickness error. This may be due to the fact that in the actual processing of the inner and outer surfaces, the tool is always processed from the flange position to the dome. And spherical shell part is a thin-walled part, which the rigidity is insufficient. In the top, the surface error and the wall-thickness error are larger. The main reasons may be that there is a built-up edge in machining process, the tool installation center and the rotation center of the workpiece are not on the same line, there are tool setting errors in the x and z directions, and poor processing conditions. Relevant research will be further carried out.

5. Conclusions

This paper proposes a method for measuring the wall-thickness of thin-walled spherical shell parts. Experiments are conducted on a spherical shell part with an outer diameter of Φ210.6 mm and an inner diameter of Φ206.4 mm. The meridian trajectory and the concentric trajectory are used to measure the spherical shell.

1. After removing the data points near the top, the surface error of the outer surface of the spherical shell is about 5 μm, and the surface error of the inner surface is about 6 μm, and the wall-thickness error is about 6 μm with meridian trajectory.

2. After removing the data points near the top, the surface error of the outer surface of the spherical shell is about 5 μm, and the surface error of the inner surface is about 8 μm, and the wall-thickness error is about 7 μm with concentric trajectory.

3. The meridian trajectory measurement can more accurately reflect the wall-thickness information at the top of the sphere. Therefore, compared with the concentric trajectory, the meridian trajectory is used to measure spherical shell parts to better reflect the surface shape and wall thickness information.

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