Deviation analysis of wall thickness measurement for tube parts with large depth to diameter ratio

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Abstract. In view of the requirement of the measurement on wall thickness of deep long tube parts, the paper uses ultrasonic thickness gauge without coupling agent to measure in the tube. The included angle of actual measuring plane and ideal measuring plane and the effect law on measurement accuracy of the offset between rotation center and theoretical axis on the measurement accuracy is studied, and the difficulties associated with included angle, offset and measuring deviation are solved in the study. The mathematical model of the deviation influence of included angle and offset on the wall thickness is established, and the model is verified by contrast experiments, which provides technical guidance for the installation of ultrasonic thickness gauge.

Introduction

In the field of petroleum transportation, the wall thickness of transportation pipeline determines its service life[1]. In the military field, the wall thickness of the gun barrel directly determines the shell velocity, flight stability and service life of the barrel. Therefore, it is necessary to check whether the wall thickness meets the requirements before the deep long tube parts produced from the factory[2]. In the measurement process of the wall thickness of the deep long tube parts, because the micrometer or vernier caliper can only measure the wall thickness of the edge of the steel tube, the ultrasonic thickness gauge is generally used for measurement in order to obtain the wall thickness value of the non-edge part of the tube parts [3]. The principle of measurement is: The wall thickness of the entire shaft section is obtained by rotating the ultrasonic thickness gauge probe with the same section of the tube parts. Taking multiple sections for measurement, then the wall thickness data of the whole tube part is obtained through data fitting[4、5]. However, the measurement method is carried out in an ideal situation. In practical application, this method will be affected by the angle α between the rotation cross section of the ultrasonic thickness gauge probe and the actual axis section of the tube parts and the influence of ultrasonic probe of eccentricity e, leading to produce measurement deviation, which causes that the unqualified parts are considered to be qualified, and the original qualified parts are considered to be unqualified. On one hand, it will lead to a great decline in the service life of the tube parts, and on the other hand, the qualified rate of the products will be reduced[6]. Therefore, it is necessary to further study the deviation in the measurement process.

Deviation Analysis of Current Measurement Method

First, the deviation of measuring the wall thickness caused by the angle α between the rotation cross section of the ultrasonic thickness gauge probe and the actual axis section of the tube parts is analyzed.

As shown in Fig. 1, due to the deviation of positioning, the angle between the rotation cross section of the ultrasonic thickness gauge probe and the actual axis section of the tube parts is α. From the point of view of the "A" of the rotating plane, which is perpendicular to the rotation cross section of the ultrasonic thickness gauge probe, see Fig. 1, in the rotating plane, the inner wall and the outer wall of the tube parts are projected into two concentric ellipses of O_1 and O_2. The inner wall radius of tube parts is set as R, and the wall thickness is set as H. For ellipse O_1, its long axis is $a_1 = \frac{R}{cos\alpha}$, its short axis is $b_1 = R$. For ellipse O_2, its long axis is $a_2 = \frac{R+H}{cos\alpha}$, its short axis is $b_2 = R + H$.

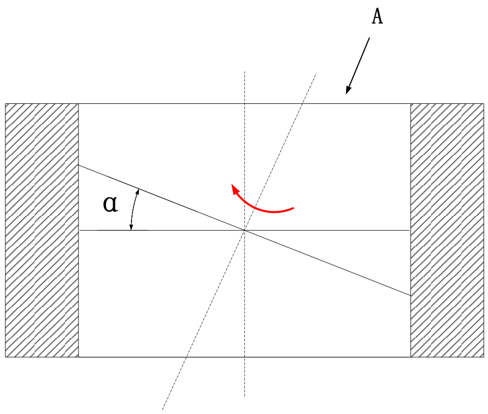

Fig. 1 The Angle α due to the positioning deviation

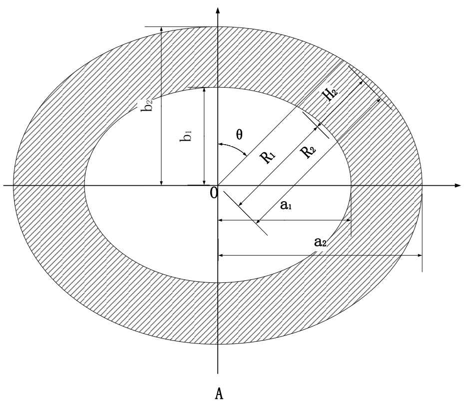

Fig. 2 The projected plane

The following is a calculation analysis of the measurement deviation of the wall thickness due to α.

Set the distance from any point on elliptic to elliptic center for r.

Assuming elliptic equation: $\begin{cases} x = a\cos t \\ y = bsint \end{cases}$ (1)

So: $\frac{y}{x} = cot\theta = \frac{b}{a}\tan t$ (2)

$r^2 = x^2 + y^2 = a^2(\cos t)^2 + b^2(sint)^2 = (cost)^2[a^2 + b^2(tant)^2]$ (3)

Putting (2) into (3):

$$r^2 = (cost)^2[a^2 + a^2(cot\theta)^2] = \frac{a^2(cost)^2}{(sin\theta)^2} \quad (4)$$

From (2):

$$\frac{a^2}{b^2}(cot\theta)^2 = (tant)^2$$

$$\frac{a^2}{b^2}(cot\theta)^2 + 1 = \frac{1}{(cost)^2} \quad (5)$$

Putting (5) into (4):

$$r^2 = \frac{a^2b^2}{a^2(cos\theta)^2+b^2(sin\theta)^2} \quad (6)$$

$$\therefore r = \frac{ab}{\sqrt{a^2(cos\theta)^2+b^2(sin\theta)^2}} \quad (7)$$

Putting a_1, b_1 and a_2, b_2 respectively into (7):

$$r_1 = \frac{R}{\sqrt{(cos\theta)^2+(cos\alpha)^2(sin\theta)^2}} \quad ; \quad r_2 = \frac{R+H}{\sqrt{(cos\theta)^2+(cos\alpha)^2(sin\theta)^2}} \quad (8)$$

$$H_2 = r_2 - r_1 = \frac{H}{\sqrt{(cos\theta)^2 + (cos\alpha)^2 (sin\theta)^2}}$$

$$\varDelta H = H_2 - H = \frac{H}{\sqrt{(cos\theta)^2 + (cos\alpha)^2 (sin\theta)^2}} - H \quad (9)$$

According to formula (9), the factors influencing the measurement of wall thickness include the angle α between the rotation cross section of the ultrasonic thickness gauge probe and the actual axis section of the tube parts, the thickness H of tube parts and the circumferential rotation angle θ, which are independent of the radius of tube parts.

Second, the deviation of measuring the wall thickness caused by the eccentricity e is analyzed.

As shown in Fig. 3, due to installation deviation, the axis of the probe will not pass through the rotating center, resulting in an eccentricity e. The inner diameter of tube parts is set as R_1, the wall thickness is set as H, so $R_2 = R_1 + H$.

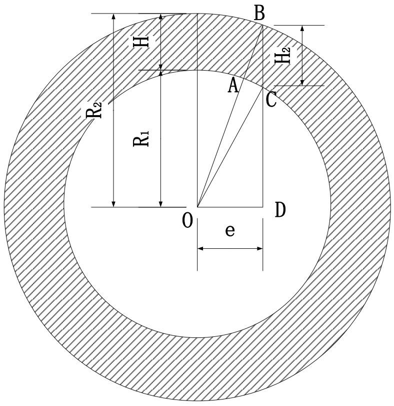

Fig. 3 The eccentricity *e* due to installation deviation

It can be seen from the geometric relationship that:

$$CD^2 = OC^2 - OD^2 = R_1^2 - e^2 \quad (10)$$

$$BD^2 = OB^2 - OD^2 = (R_1 + H)^2 - e^2 \quad (11)$$

$$\varDelta H = H_2 - H = \sqrt{(R_1 + H)^2 - e^2} - \sqrt{R_1^2 - e^2} - H \quad (12)$$

According to formula (12), the factors influencing the measurement of wall thickness include the eccentricity e and the radius of tube parts R_1.

Experimental Design

Experimental Device. The specific experimental device is shown in Fig. 4. In the figure, label 1 is the ultrasonic thickness gauge probe, which is used to measure the wall thickness, the model is LINGSHENGKEJI ETG100 with a resolution of 0.001mm. Label 2 is the manual rotation fine tuning platform, which is used to adjust the circumferential rotation angle θ, the model is SIGMA KSP-406M with an accuracy of 0.1°. Label 3 is the manual radian fine tuning platform, which is used to adjust the angle α between the rotation cross section of the ultrasonic thickness gauge probe and the actual axis section of the tube part, the model is SIGMA KOKI with an accuracy of 0.1°. Label 4 and label 5 are manual displacement fine-tuning measuring platforms for adjusting the rotation center of the measuring gauge probe and the actual center of tube parts to be concentric, as well as adjusting eccentricity e, the model is SELN LGX60-R with an accuracy of 0.01mm. Label 6 is the standard parts for tubes.

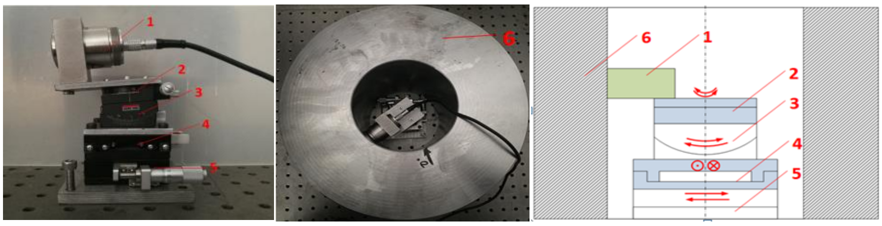

Fig. 4 The specific experimental device

Experiment to verify formula (9). It can be seen from the above analysis that, when exploring the influence of the angle α between the rotation cross section of the ultrasonic thickness gauge probe and the actual axis section of the tube parts, the influencing factors include the wall thickness H and the circumferential rotation angle θ, so the design experimental conditions are shown in Table 1.

Table 1 Experimental condition

Experiments number	α（°）	H（mm）	θ（°）
1	0	26	0,10,20……350
2	3	26	0,10,20……350
3	6	26	0,10,20……350
4	9	26	0,10,20……350
5	12	26	0,10,20……350
6	0	94	0,10,20……350
7	1	94	0,10,20……350
8	2	94	0,10,20……350
9	3	94	0,10,20……350
10	4	94	0,10,20……350

The comparison between the scatter diagram of deviation ΔH and rotation angle θ made in the experiment and the curve diagram of theoretical formula (9) made through Labview is shown in the figure. When H=26mm, α=3°, the results are shown in Fig.5. When H=26mm, α=6°, the results are shown in Fig.6.

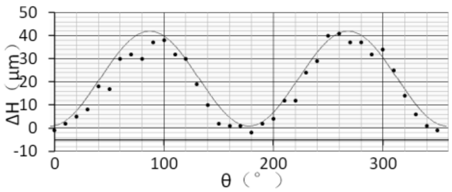

Fig. 5 H=26mm, α=3°

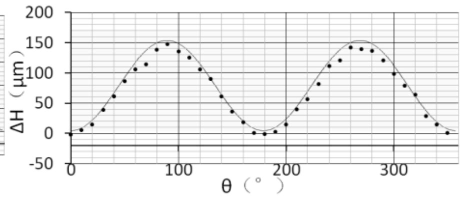

Fig. 6 H=26mm, α=6°

When H=26mm, α=9°, the results are shown in Fig.7. When H=26mm, α=12°, the results are shown in Fig.8.

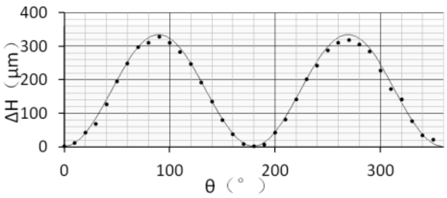

Fig.7 H=26mm, α=9°

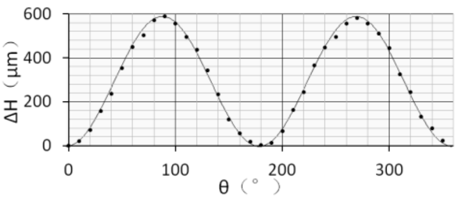

Fig.8 H=26mm, α=12°

When H=94mm, α=1°, the results are shown in Fig.9. When H=94mm, α=2°, the results are shown in Fig.10.

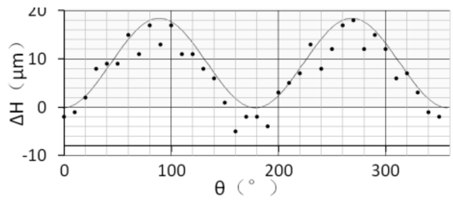

Fig.9 H=94mm, α=1 °

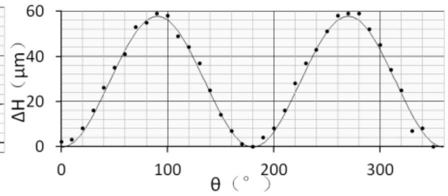

Fig.10 H=94mm, α=2 °

When H=94mm, α=3 °, the results are shown in Fig.11. When H=94mm, α=4 °, the results are shown in Fig.12.

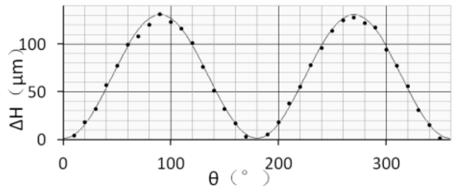

Fig.11 H=94mm, α=3 °

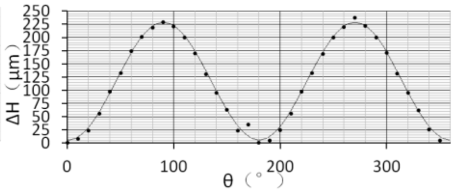

Fig.12 H=94mm, α=4 °

Experiment to verify formula (12). It can be seen from the above analysis that the influencing factors include wall thickness H and radius R of tube parts. Therefore, experimental conditions are designed as shown in

Table 2.

Table 2 Experimental condition

Experiments number	H（mm）	R（mm）	e（mm）
1	26	72	0、1、2……12
2	26	97	0、1、2……12
3	26	175	0、1、2……12
4	94	72	0、1、2……12
5	94	97	0、1、2……12
6	94	175	0、1、2……12

The scatter diagram of deviation ΔH and eccentricity e made according to the experiment and the curve diagram of theoretical formula (12) made through Labview are shown in the figure. When H=26mm, R=72mm, the results are shown in Fig.13. When H=26mm, R=97mm, the results are shown in Fig.14. When H=26mm, R=175mm, the results are shown in Fig.15.

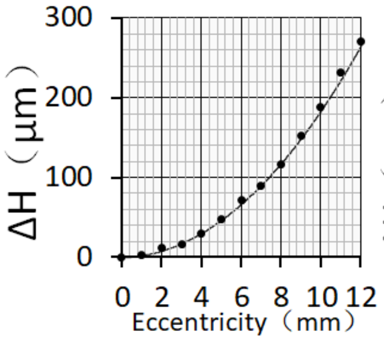

Fig.13 H=26mm, R=72mm

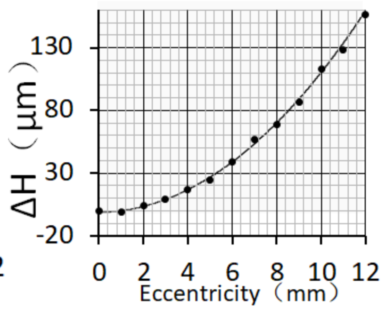

Fig.14 H=26mm, R=97mm

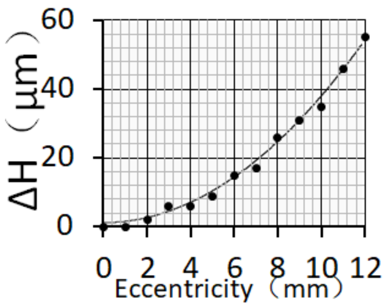

Fig.15 H=26mm, R=175mm

When H=94mm, R=72mm, the results are shown in Fig.16. When H=94mm, R=97mm, the results are shown in Fig.17. When H=94mm, R=175mm, the results are shown in Fig.18.

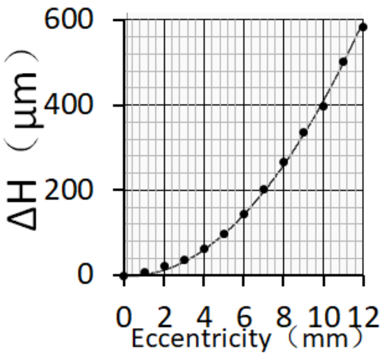

Fig.16 *H*=94mm, *R*=72mm

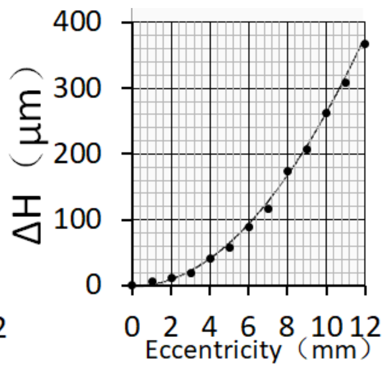

Fig.17 *H*=94mm, **R**=97mm

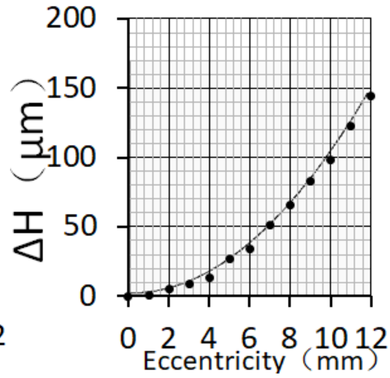

Fig.18 *H*=94mm, *R*=175mm

Summary

This paper analyzes the influence of two main factors on the measurement of wall thickness. By establishing the mathematical model, the theoretical formulas are given. Then, the theoretical formulas given are verified by experiments. In terms of engineering application, the formulation in this paper can be used to select the appropriate positioning deviation and installation deviation on the premise of given wall thickness measurement precision. On the basis of guaranteeing the measurement precision, the difficulty of measurement can be reduced.

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