Research on Automatic Labeling of Contact Profiler Based on Big Data

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Abstract. This article mainly studies the problem of labeling various parameter values of the contact profiler. The contour size of the instrument is analyzed by the least square method for the mathematical theory, and the data analysis information of each line and arc is established based on the background of big data. As a result, the corresponding mathematical model is established to realize the labeling of outline dimensions. First, perform precision processing on the horizontal data of the workpiece, use Excel software to make a scatter diagram, use the difference method to quickly search and locate the special inflection point coordinates, borrow these feature points to obtain the dimension of each data in turn, and combine the equations of straight lines and circles Find out the width and radius of the naco, find out the various indicators in turn, and finally sort and summarize them through the table. Next, the tilt data and the original data given for the workpiece are represented by a scatter graph. Using coordinate rotation and translation, the tilt angle is 7°24′59″ clockwise and the radian is -0.13017. Compare the two sets of data After the difference, finally use segmented fitting to carry out horizontal correction.

Keywords: Least squares method, Big Data, High precision, Difference method, Coordinate rotation.

1. Introduction

The profiler is a two-coordinate measuring instrument, which consists of a working platform, a fixture, a workpiece to be measured, a probe, a sensor, and a servo drive. The working principle of the contact profiler is that the probe touches the surface of the workpiece to be measured and slides at a constant speed. The sensor senses the geometric changes of the measured surface, samples them in the X and Z directions, and converts them into electrical signals[1]. The electrical signal is amplified and processed, converted into a digital signal, and stored in a data file. In an ideal situation, the contour curve should be smooth, but due to the problems of probe contamination, probe defects, and inaccurate scanning position in the contact profiler, the detected contour curve is rough and uneven, which gives the workpiece shape Accurate labeling has an impact.
In order to simplify the problem, it is assumed that the contour of the measured workpiece is a plane curve composed of straight lines and arcs (see Figure 1). Please establish a mathematical model and study the following questions based on the level and tilt measurement data of a certain workpiece. According to the measurement data provided by a workpiece in the horizontal state, its contour line is shown in Figure 1. Please mark the parameter values of the contour line: slot width (such as $x_1$, $x_3$, etc.), arc radius (such as $R_1$, $R_2$, etc.), the distance between the center of the circle (such as $c_1$, $c_2$, etc.), the length of the arc, the length of the horizontal line segment (such as $x_2$, $x_4$, etc.), the length of the diagonal line segment, the angle between the diagonal line and the horizontal line (Such as $\angle 1$, $\angle 2$, etc.) and the height of the chevron line ($z_1$). When the same workpiece is measured in different times, the calculated value of the contour parameters will also be different due to the different placement angle and position of the workpiece. The other set of data gives the measurement data of the contour of the workpiece 1 at an angle of inclination and some horizontal displacement. Please calculate the inclination angle of the workpiece according to the data and make horizontal correction. After the data is corrected, compare the difference between the calculated values of each parameter of Workpiece 1 in the two measurement states.[2-4]

![Figure 1](image.png)

**Figure 1.** The contour of the workpiece measured in a horizontal state

2. Method

2.1. Preparation before solution

The contact profiler has high precision, and the provided workpiece data displays 12 decimal places. In order to simplify the problem, the contour line of the measured workpiece is regarded as a plane curve composed of straight lines and arcs. Therefore, the data is preprocessed before the modeling and analysis, and the X and Z coordinate data of the workpiece are reserved with 5 decimal places.

2.2. Draw contour map

Use Excel software to make a scatter plot of the preprocessed data and mark the special points. Denoted as $i=1,2,\ldots,39$; including the inflection point, as shown in Figure 2.
2.3 Summary of solution method
The first step is to calculate the included angle. First, calculate the difference between the processed data. The calculation formula is as follows:

\[ \Delta Z_i = Z_{i+1} - Z_i \]  
\[ \Delta X_i = X_{i+1} - X_i \]  

Next, calculate the ratio of formula (3) on the result data, and find the slope:

\[ k = \tan(\theta) = \frac{\Delta Z_i}{\Delta X_i} \]  

Finally, the angle formula obtained by using the inverse trigonometric function is:

\[ \theta = \arctan \left( \frac{\Delta Z_i}{\Delta X_i} \right) \]  

The second step is to calculate the distance between two points. According to the marked points, use the distance formula between two points to calculate the width of the notch and the length of the horizontal line segment:

\[ d = \sqrt{(a_1 - a_2)^2 + (b_1 - b_2)^2} \]  

The third step is to calculate the arc radius. To calculate the arc radius, you need to determine the coordinates of three points and use the arc radius formula to find the radius, where the arc radius is:

\[ (X - X_i)^2 + (Z - Z_i)^2 = r^2 \]  

The fourth step is to calculate the arc length. Within the range of arc length, find two coordinates with approximately equal ordinates, find the chord length according to the coordinates, and finally use the arc length formula to calculate:

\[ l = \frac{n \pi r}{180} \]  

3. Results

3.1. Analysis of Simple Marking Results of Contact Profiler
The result of the solution is the difference method to quickly search for coordinates A1 (49.7909, -1.7924) with serial number 6378, coordinates A3 (51.2108, -4.7559) with serial number 9149 and
coordinates A5 (52.6070, -1.9301) with serial number 12009, And so on, respectively find the inflection points in Figure 2, and use the least square method to mark the parameter values of the contour line according to the calculation formula 1-7.

**Table 1.** The slope and horizontal angle of the workpiece

| order i | Slope k  | Angle θ  |
|---------|----------|----------|
| 1       | -2.23609 | 114.5    |
| 2       | -0.00115 | 107.32   |
| 3       | -3.27538 | 106.58   |
| 4       | -2.99436 | 108.28   |
| 5       | -2.22372 | 114.12   |
| 6       | -0.00634 | 116.37   |
| 7       | -0.01781 | 164.42   |
| 8       | -0.71906 | 144.16   |

It can be found from that Table 1 is the slope and horizontal angle of the workpiece in Figure 1 obtained by formula 1-4.

**Table 2.** Notch width of the workpiece

| xi     | Notch width |
|--------|-------------|
| x1     | 2.9160      |
| x3     | 1.7883      |
| x5     | 2.5127      |
| x7     | 9.9982      |
| x11    | 7.9978      |
| x13    | 7.5018      |

**Table 3.** The length of the horizontal line of the workpiece

| xi     | Notch width |
|--------|-------------|
| X2     | 1.3708      |
| X4     | 4.4842      |
| X6     | 5.0041      |
| X8     | 2.4992      |
| X9     | 0.9995      |
| X10    | 4.5030      |
| X12    | 4.5014      |

It can be found that Table 2 and Table 3 are the results of using formula 5 to find the width of the notch and the length of the horizontal line.

**Table 4.** Arc radius of the workpiece

| Ri     | Arc radius |
|--------|------------|

Table 5. Arc length of the workpiece

| Li  | Arc length |
|-----|------------|
| L1  | 1.0603     |
| L2  | 0.7517     |
| L3  | 0.8114     |
| L4  | 1.1266     |
| L5  | 1.31       |
| L6  | 5.3823     |
| L7  | 2.9915     |

In this paper, Lingo software is used to quickly calculate the arc radius of the workpiece in Figure 1, and the calculation results are shown in Table 4. Next, use the formula 7 to quickly calculate the arc length of the workpiece in Figure 1 with Excel software. The calculation results are shown in Table 5.

### 3.2. Research on the marking results after the profiler is tilted

The common error of the contact profiler is the position error of the measuring object, and there is a certain angle between the coordinate of the measuring object and the measuring system. Therefore, the processing data is effective. The position points at equal intervals of 0.0005 are adopted, and the side head of the sensor is placed on the workbench and rises with the workbench at equal intervals, and the value of the sensor without compensation is recorded. According to the compensation formula, a higher-order equation is used to fit the actual displacement.

When the same workpiece is measured in different times, the placement angle and position will be different. Therefore, the tilt data of the workpiece is preprocessed before modeling and analysis. The X and Z coordinate data in the tilt data retain 5 decimal places. Since the data is different due to different angles and positions, compare the original data of the workpiece and the tilt data by drawing a scatter diagram in Excel, as shown in Figure 3.
Figure 3. Scatter plot of workpiece raw data and tilt data

As shown in Figure 3, the required tilt angle needs to find any two points on the tilted contour map. According to formula 3 in the text, the slope of the workpiece during measurement can be calculated, and then the tilt angle and radian can be calculated according to formula 4. The final result is that the tilt angle is 7° 24′ 59″ clockwise, and the radian is -0.13017. To calibrate the data in Figure 3, you first need to find the two key points of the data, that is, to find the common reference point. After the reference point is determined, it can be taken as the coordinate origin. Then the tilt data is corrected according to the coordinate conversion formula, and finally The data after coordinate transformation is translated horizontally to obtain the final ideal value. High-level curve fitting is performed on some curve segments in the workpiece to achieve the best effect.

Figure 4. Coordinate conversion diagram

4. Conclusions
The model map established by the coordinates in this paper can roughly measure the contour map. Due to the large amount of data, there are errors in the labeling of various parameter values. Therefore, the three steps of "find reference point-correction-translation" are used to analyze the errors in both the horizontal and numerical directions. For some curve segments, a polynomial fitting error compensation method is used to make the contact profiler achieve the best automatic marking result.

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