Accuracy improvement method of eddy current sensor

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Abstract

Eddy current sensor is widely used in industry,because of its non-contact measurement, and strong anti-interference, etc,. However, its accuracy is difficult to reach the micron-level. This paper uses the accuracy analysis theory and the software error correcting technology to calibrate measurements. Besides, it gives an effective principle, which uses "minimum interval" and "maximum ranges segment" to determine the optimum operating ranges of eddy current sensor, to improve the sensor's measurement accuracy. This method is used in commercial eddy current sensor, resulting from the improvement of precision.

1.Introduction

Eddy current sensor uses eddy current principle [1], through measuring the relative position of metal caused by different sensor coil inductance,impedance changes,to achieve displacement measurement.With its non-contact measurement, anti-jamming ability,high accuracy, good dynamic response,eddy current sensor is widely used in the production line of high-speed motion state of axial, radial displacement,and the dynamic displacement measurements. However, he temperature changing of eddy current probe,current volatility and complexity of the electromagnetic field, leading to sensor measurement accuracy more difficult to achieve micron level.The current commercial eddy current sensor accuracy is usually 10 μm,to reach 4μm accuracy of the above,the cost significantly increases. Home and abroad, researchers in enhancing the sensor precision theoretical and technical aspects do a large number of studies [2-8],such as associated with optimal sensor parameter method [3],the differential form of sensor method [4],Using thermal devices or temperature characteristics of electronic components, for the temperature compensation method [5],look-up table compensation method [6],and other methods to improve instrument precision. In this paper, "minimum interval" and "maximum ranges segment," the principles of interval selection section, selects the eddy current sensor to meet the accuracy requirements of the best working range of methods to improve measurement accuracy. This approach,with high stability, reliability, good practical significance and practical engineering value, is a useful complement to sensor measurement theory.

2. Test Device

In this article,we use OD-900803-03-04-20-00 models of eddy current sensor, production index as follows: range for 0.8-2.80mm , standard sensitivity of 2V/mm, resolution of 0.5μm, measurement accuracy of 10μm, work voltage of 24V. Calibration of measuring instruments is the use of sub-micron Inductance Sensor (TESA ERONIC TT 80).Choose USB5935 for data acquisition card, sampling frequency 500Hz; use steel as the measurement object, and two instruments measure simultaneously to obtain the displacement changes of inductive displacement sensors and the voltage change of eddy current sensor. For ease of using, Calibration accuracy Commercial eddy current sensor are all using a linear function as the fitting function, this article also uses a linear function for error correction. The fitting error correction makes the range of eddy current sensor greater than 1mm, accuracy of 4 μm. Because the output voltage of eddy current sensor is the amount of sensitivity of 2V/mm, that is: 2mv/μm.The relationship between static precision and standard deviation of the sensor is between $\gamma= \pm 3\sigma$[1], it is required the standard deviation of the final fitting of eddy current sensor should be less than 0.667μm, which 1.334mv.

Working process is as follows: Steel materials 2 is used as a measurement object, the full range of eddy current sensor (0.80 ~ 2.80 mm) is divided into 80 equally spaced points, preheat half an hour after startup. Measurement process: rotating micro platform 1, every 25 μm, read out the the voltage values of eddy current 3 and the displacement values of inductance displacement sensor 4, and record data. Inductive sensor 3 outputs displacement value through display 7,eddy current transducer 3 processes feeling of displacement after the front-end device 5 (voltage of front-end device 5 is provided by the voltage converter 6), it is converted into the corresponding voltage quantity, to be displayed through data acquisition card 7 to the computer 9.

3. The Original Accuracy OF Eddy Current Sensor

Measurement should take external factors and the noise interference into consideration.For a single displacement, the first 1000 data of the data acquisition card are averaged as the value corresponding to the eddy current sensor output voltage of the point.While for the point of poor stability in multiple measurements , select the maximum error value. Measured once every 25μm, and get 81point in the full range (0.80 ~ 2.80 mm) , as shown in Table 1.

X Displacement（μm）	800	825	850	875	900	925	950	975	……
Y Voltage capacity（mv）	1000.49	1054.07	1107.65	1160.52	1213.33	1266.57	1319.84	1371.99	……

Table.1 The experimental data

Least squares fitting of the measured data obtains residual error which is shown in Figure 2.The analysis of known, Eddy current sensor has a large residual volatility in the full range , so accuracy of direct linear fitting can only reach 10 μ m. However, in the range of other areas around the residual error is less volatile. the residual error changes in one direction, with regulary, linear performance is better.To meet the 4μm accuracy,the appropriate range of displacement measurement is choosed to improve eddy current sensor measurement accuracy. To select the ranges of 800 ~ 1200 μm,1200 ~ 2200 μm, 2200 ~ 2800 μm intuitively and validation for accuracy are blindness. The best working range of is determined by The principles of "minimum interval" and "maximum

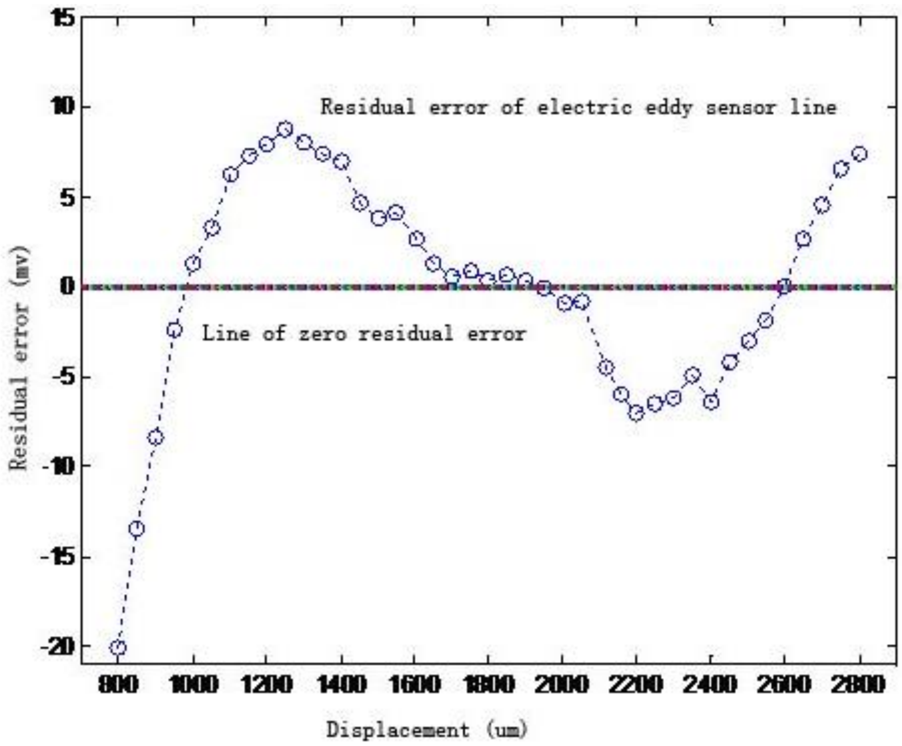

Figure.2Image of measurement data residual error

ranges segment" depending on the measurement accuracy instruments.

4."Minimum Interval" And "Maximum Ranges Segment", The Method OF Working Interval

Eddy current sensor voltage and the displacement volume ratio on the test

↓

Mathematical model to establish the range and standard deviation of segment

↓

Given error range, the number ofsegments according to the minimum and maximum range interval principle segment, selecting range

Figure.3 Method flowchart

The process is shown in Figure 3 .Firstly, select the high-precision measuring instruments as the reference standard to get calibration accuracy of eddy current sensor, the value of the voltage relatived to variable displacement is obtained.

Then based on the value of the voltage is relatived to variable displacement of eddy current sensor and the principle of least squares [7], meaning the function between the sampling data and the the data of subsequent establishment,which means making linear fit from the first datum to the last by turn.That is to say ,establish the first point and second point data linear fitting function is followed by setting up the first, second, and third data linear fitting function then the first, second, third and fourth point data fit the linear relationship. The rest can be done in the same manner, until the last point data's function is set and error calculation is needed every time after the mode is constructed. Subsequently start from the second data point to establish function model and calculate The model's error in turn according to the above method . And so on, the mathematical modeling and the calculation error of all data points behind is completed.Then the best job interval is determined according to the given error range.the voltage quantity interval which accords with the condition is choiced according to the calculation results and the practical demand of error.At this time, the number of interval is too large, and the interval model is different and it is against the demand of actual research.

According to the need, the optimal selection principle of “minimum interval” and “maximum ranges segment” is presented to determine the best working ranges. The principle of the minority working period is used to reduce the number of different mathematical models that accords with the condition, the data is contained in several intervals, in order to use the fewer mathematical models to improve the accuracy.the selection principle of “the maximum range” gives the maximum amount of data that contains the largest segment of eligible interval interval, in the appropriate conditions, it helps researchers to chose a single mathematical model segment range to improve accuracy.

Obviously, the “maximum ranges segment” is included in the interval paragraph of “minimum interval” . In meeting the conditions of the range and accuracy , the "maximum ranges segment" Should be choosed to obtain the method of interval, because the mathematical model is single and it is easy to use.Otherwise, the method of the“minimuminterval”method should be selected to gain several interval which is accord with the requirement of accuracy and span conditions,as the intervals of sensors, and these intervals must be connected, overlap is allowed. though the quantity of mathematical model is increased, it can reach the increased of the requirements within range of the measurement precision.

Use matlab software to program, program flow chart is shown in Figure 4.

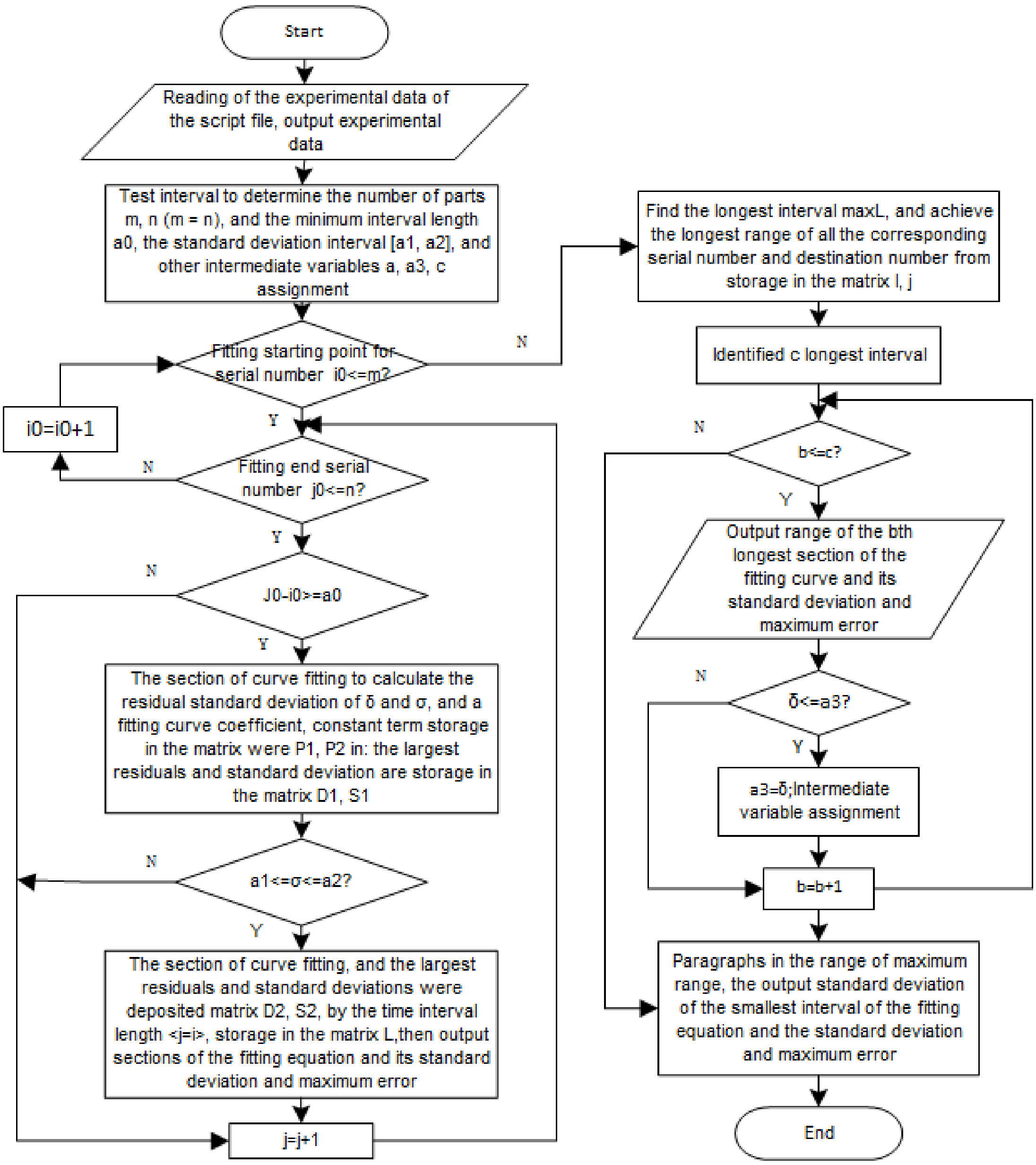

Figure.4 Process flow chart

5.To Determine The Best Working Range OF Eddy Current Sensor

The measurement data is processed according to the principle. To establish a function and calculate the standard error estimates from the first point of beginning to all the points in turn. For example Least-square fitting method for linear is used to calculate the first point (800 μ m) with other 7 points , the functional as follows:

y=2.1233×x-697.6170

By the calculation formula of sample standard deviation,

$$\sigma = \sqrt{\frac{1}{k-1}\sum_{i=1}^{k}(\hat{y}_i - \bar{y}_i)^2}$$

In the formula, $\hat{y}_i$ -- calculate according to the calculation of fitting the expectations;

The standard deviation of the 7 points fitting function is:

$$\sigma = 0.3884\text{mv}$$

Maximum deviation is:

$$\delta = 0.6058\text{mv}$$

In turn, the correlation function (table omitted) ,standard deviation and maximum deviation of the interval type is obtained,as shown in Table 2.

Point and interval	[1,2]	[1,2,3]	[1,2….81]	[2,3]	[2,3,4]	…….	[2,3...81]	[3,4]	…
Displacement range (μm)	[800,825]	[800,850]	[800,2800]	[825,850]	[825,875]	…….	[825,2800]	[850,875]	…..
Standard deviation σ (mv)	0	0	6.3833	0	0.205	…….	5.5275	0	…..
Maximum deviation δ （mv）	0	0	17.9251	0	0.2367	……	13.2591	0	…..

Table.2 The range of error

According to the needs of accuracy and range, the standard deviation is given as 1.334mv, and the range is larger than 1mm.

The number of the segments of the displacement of the choice interval for interval is eight according to the principle of minimal interval (the minimum length displacement is 1mm) , as shown in Table 3.

Displacement range (μm)	[1150,2150]	[1150,2200]	[1150,2350]	……..	[1350,2350]
Standard deviation σ (mv)	1.1744	1.2759	1.3272	………	1.1168
Maximum deviation δ （mv）	2.5775	2.8017	3.1101	……..	2.2266

Table.3 Meet the "minimum interval" displacement range

The displacement interval [1150,2350] is choiced according to the principle of "maximum ranges segment" , as shown in Table 4.

Displacement range (μm)	Standard deviation σ (mv)	Maximum deviation δ （mv）	Mathematical model
[1150,2350]	1.3272	3.1101	y =1.9983×x-564.7241

Table.4 Satisfy the "maximum ranges segment" displacement range

Due to the displacement interval of[1150,2350] is accord with the demand of precision and the requirement of ranges according to the principle of "maximum ranges segment", Therefore, select [1150,2350] interval as workspace.

To calculate standard variance σof the interval [1150,2350] precision calibrated according to the eddy current sensor sensitivity 2mV/m, the equivalent of

$$1.3272(\text{mv})/2(\text{mv}/\mu m)=0.66\,\mu m<0.667\,\mu m$$

the maximum deviation δ

$$3.1101(\text{mv})/2(\text{mv}/\mu m)=1.555\,\mu m$$

At this time the accuracy of sensor $\gamma = \pm 3\sigma = \pm 1.98$,.The accuracy is improved 2 times more than original sensor .

6. Conclusions

The key of the approach to upgrade for the accuracy of eddy current sensor is based on the principles of “minimum interval” and “maximum range segment” to optimize the sensor's working interval, remove the interval of large errors, poor stability, in order to meet the engineering needs,but it costs the lossing of measurement range.The high stability of this method is demanded for the instrument,and the system error is the main source of error, otherwise it is difficult to obtain high-precision ranges of available segment. Extraction of the best working range is not only applicable to eddy current sensors, but also for other sensors such as capacitive sensors, CCD laser measurement system .The method has good practical significance and engineering value.

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