Laser on-line Thickness Measurement Technology Based on Judgment and Wavelet De-noising

Xu Anchong, Xu Qingquan, Chen Gong, Zhu Xifang, Zhang Hua and Liu Xiaojun
Changzhou Institute of Technology, Changzhou 213022, China
Tel.: 13921034125
E-mail: jackyxac@163.com

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Abstract: Lithium battery coating thickness is measured by sensor using laser triangulation. The algorithm based on threshold judgment and multi-scale wavelet is realized for noise high-frequency reduction of lithium battery film thickness systems. The result shows that compared with the unique multi-scale wavelet de-noising, the method applies to different lengths and discontinuous of coating thickness measurement. Copyright © 2014 IFSA Publishing, S. L.

Keywords: Laser, Threshold, Multi-scale Wavelet, Film thickness.

1. Introduction

With the rapid development of new resources industry, more importance is attached to lithium battery coating machine film thickness measurement technology. Traditional off-line, static and touching measuring technology fails to realize timely control of production process and seriously affects product precision as well as production efficiency cannot meet the dynamic measuring requirements of modern processing. Therefore, it is of significant importance to apply on-line, non-touching measuring. Trigonometric displacement method has now become mainstream off-line and static measurement method due to its characteristics such as small volume, easy integration, high measuring precision, low requirements on installment, and no claim for security precautions.

There mainly exist static error and dynamic error caused by moving mechanism in lithium battery film thickness on-line measuring equipment. Static error resulting from system and external temperature can be removed via system calibration. Traditional dynamic error eliminating method lays more emphasis on time and frequency domains, which has fast response time but not so ideal filtering effect. The application of multi-scale wavelet de-noising can meet actual production requirements. Traditional multi-scale wavelet de-noising only applies to long or continuous film coating, but when used to measure short film thickness, the measuring results are seriously distorted [1, 2].

In sum, lithium battery coating dynamic scanning by laser sensor is conducted via dynamic scanning system setting and C-frame moving structure control. On-line measurement of lithium battery film thickness by laser sensor is carried out via trigonometric displacement method. Dynamic de-noising is realized via improved multi-scale wavelet algorithm [3].
2. Laser Displacement Method

Fig. 1 is schematic diagram of thickness measurement by laser sensor. Fig. 2 shows thickness measuring principle based on trigonometric displacement method. Coating thickness measuring formula is \( W = D - D_1 - D_2 \). Fixed distance between upper and lower laser ends is \( D \). Distance between upper laser end and upper film surface is \( D_1 \). Lower laser end and lower film surface is \( D_2 \). Measured coating thickness value is \( W \) [4-6].

![Fig. 1. Schematic diagram of thickness measurement by laser sensor.](image1)

![Fig. 2. Measuring principle of up and down laser sensor.](image2)

3. Static Error Restraint

Vibration frequencies of C-frame structure are the same and mainly below 130 Hz at different scanning speeds. Because vibration excitation with high frequency is decreased to a small value by C-frame structure, while that with low frequency is magnified due to its similar natural frequency to C-frame structure. Therefore, low frequency vibration has a greater influence on measuring precision.

In lithium battery film thickness on-line measuring equipment, the factors affecting measuring precision are various and complex. The errors caused by internal elements of measuring equipment and external temperature are static errors, while those resulting from guide rail load, friction and external vibration are dynamic errors. The former can be eliminated via calibration. When C-frame structure is being static, the distance between upper and lower sensors is determined via standard gauge of 1110 \( \mu \)m thickness, then, measurement of 1140 \( \mu \)m thickness standard gauge is conducted. Fig. 3 shows the value difference between actual and measured value of standard gauge (sampling frequency being 1 kHz and thickness being 1140 \( \mu \)m). The value difference is the system error after system calibration, with mean square deviation being 0.344 \( \mu \)m. Experiments demonstrate that major system errors can be eliminated via calibration, thus obtaining ideal target error range.

![Fig. 3. The standard block error data.](image3)

4. Dynamic Error Restraint

4.1. Multi-scale Wavelet De-noising

The elimination of dynamic errors can be achieve via improving measuring equipment and curbing vibration caused by external vibration excitation. However, this article focuses on de-noising based on multi-scale wavelet technology. Coating thickness by actual measurement is the typical non-stationary signal. This article mainly deals with thickness data de-noising via multi-scale wavelet. In laser measuring system, dynamic errors in measuring system mainly include vibration frequency errors. Vibration errors are represented as high frequency signals while valid film thickness is represented as low frequency signals. In the process of error mitigation, wavelet decomposition coefficient at high frequency is made as 0 via forced de-noising of high frequency elements so as to eliminate vibration errors effects. Then, signals in valid frequency range are reconstructed. Finally, distribution signals of measured coating thickness after error mitigation processing are obtained. Experiment results show that detection reconstruction based on 7-level wavelet decomposition scale (frequency band of wavelet decomposition being illustrated in the diagram) and db4 wavelet basis function has the fewest errors, which can effectively distinguish errors and film thickness signals.
Table 1. Frequency band distribution at 7-level wavelet decomposition scale.

<table>
<thead>
<tr>
<th>Decomposition scale</th>
<th>Low frequency 7th Layer</th>
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<th>High frequency 6th Layer</th>
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<td>7.813</td>
<td>15.626</td>
<td>31.25</td>
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<tr>
<td>Ending frequency</td>
<td>7.813</td>
<td>15.626</td>
<td>31.25</td>
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<table>
<thead>
<tr>
<th>Decomposition scale</th>
<th>High frequency 4th Layer</th>
<th>High frequency 3rd Layer</th>
<th>High frequency 2nd Layer</th>
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</thead>
<tbody>
<tr>
<td>Starting frequency</td>
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<td>125</td>
<td>250</td>
<td>500</td>
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<tr>
<td>Ending frequency</td>
<td>125</td>
<td>250</td>
<td>500</td>
<td>1000</td>
</tr>
</tbody>
</table>

4.2. Experiment Results

When film is moving and C-frame structure is static, actual double coating film thickness distribution data in industrial production and level 1-7 wavelet de-noising data are shown in diagram Fig. 4. Horizontal axis represents sampling points. Vertical axis is output data. Moving speed of film is 55 mm/s.

As can be seen from the diagrams, the width of coating film is narrow and appears alternatively with lithium film. It is difficult to distinguish between coating film and lithium film via wavelet decomposition reconstruction statistics at level 5-7. The average value at level 7 is 155.4 μm, which is caused by low frequency noise of periodicity appearance of coating film and lithium film. As a result, the higher the decomposition level is, the more insignificant the periodicity is, and the more deviated filtering results are derived. However, data reconstruction at level 3 not only represents actual periodicity distribution of coating film and lithium film, but also results in relatively smooth and effective coating thickness.

Therefore, traditional multi-scale wavelet de-noising only applies to film thickness measurement with relatively long (generally longer than 900 mm) or continuous coating. In sum, as is shown in diagram Fig. 5, firstly, measured data pre-processed at the front end are processed by level-3 wavelet. Then, continuous coating film is obtained by eliminating lithium thickness according to threshold value range judgment. Finally, effective coating film thickness data are reconstructed at low frequency via 7-level wavelet decomposition.

Make threshold value range being 170-200 μm and film moving speed being 55 mm/s. Diagram Fig. 6(a) - (d) show original data of 3 scanning speeds of C-frame structure (V1, V2, V3), data processed by level 3 wavelet, threshold value output, and output processed by level 7 wavelet in conditions of static C-frame and moving film, moving C-frame structure and moving film.

Change threshold value ranges of diagrams (a) - (d) to 180 - 190, 170 - 200, 160 - 210, 150 - 220, 140 - 230, 130 - 240, 120 – 250 μm, diagram Fig. 7 shows original measured data of C-frame structure at 3 scanning speeds and output at different threshold value range in conditions of static C-frame structure and moving film, moving C-frame structure and moving film.
Fig. 6. Output Data of C-frame structure and film in different conditions.

Fig. 7. Data of C-frame structure and film in different conditions.
4.3. Experiment Analysis

When threshold value is fixed between 170 - 200 μm and C-frame structure changes from being static to moving, the non-stability of original data increases. When moving speed increases, the non-stability of output data increases and the length of data gradually decreases. However, output data at different speeds are all within film thickness range 180 - 190 μm.

When threshold value is changing and C-frame structure is static, threshold value range increases from 180 - 190 μm to 140 - 230 μm with output data within actual film thickness range. When threshold value increases from 130 - 240 μm to 120 – 250 μm, some output data exceed the actual film thickness range. For example, when C-frame structure is moving at speed V2, then the valid data threshold value range grows from 180 – 190 μm to 150 - 220 μm. When exceeding 140 - 230 μm, data outside film thickness range gradually increase with the increase of threshold value range.

In conclusion, when C-frame structure is static, original measured data are relatively stable due to the only dynamic vibration caused by moving film. The threshold value range reaches 140 - 230 μm (90 μm). When scanning speed of C-frame structure increases from V1 to V3, mixed dynamic vibration caused by C-frame structure and film gradually increases and the non-stability of original measured data increases. The maximum threshold value range is 160 - 210 μm (50 μm). In actual production, production requirements can be met when threshold value range is set between 160 - 210 μm.

5. Conclusion

Lithium battery on-line coating thickness measurement by sensor is conducted via laser trigonometric displacement method. Static and dynamic errors caused by laser thickness measurement are eliminated. The former is filtered via system calibration, the latter is eliminated (retaining the low frequency valid film thickness) by high frequency de-noising via 3 level wavelet-threshold value (160 - 210 μm) and 7 level wavelet algorithm. Experiment results show that compared with single multi-scale wavelet de-noising, such technology is more applicable to non-continuous coating film thickness measurement.

Acknowledgments

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References

[2]. Wei Tang, Guo Pu-Qu, Yue Zhao, Design for the characteristics of X ray thickness gauge data processor circuit, Journal of Hunan University of Science and Engineering, 08, 2010, pp. 22-23.