Thickness Test of Tire Film and Steel Cord Fabric with Terahertz Technology

Bailin Hang\textsuperscript{1,a}, Changxi An\textsuperscript{2,b}, Zhan Liu\textsuperscript{3,c} and Zhenya Duan\textsuperscript{4,d,*}

\textsuperscript{1,2,3,4}Qingdao of Shandong Province, China
\textsuperscript{a}hbl@wanlongsys.com, \textsuperscript{b}imanchangxi@qq.com, \textsuperscript{c}zhanliu168@qust.edu.cn, \textsuperscript{d}dzyduan88@163.com

*Corresponding author

Keywords: Terahertz Technology, Tire Film, Steel Cord Fabric, Thickness Detection.

Abstract. Uneven thickness is a familiar quality problem appear in the production process of tire semi-finished extrusion parts, which affect the performance and the lifetime of the tire, so the quality testing of thickness is very necessary. This test established a terahertz detection method with time domain approach. A static test for tire film and wire cord fabric thickness was made with the equipment of API T-Ray 5000 (USA). Time, index and thickness is obtained according to the reflection waves from different reflecting surface. The results show that using terahertz technology can detect tire wire cord fabric thickness, its accuracy and stability meet the requirements.

1. Introduction

Tire semi-finished extrusion parts production process is complicated. The quality of tire film and wire cord fabric as an important component of tire has an important impact. There are lots of research has done in many fields of terahertz application, but in the field of tire production is still a “blank space”\cite{1,2,3}. According to the terahertz characteristics of penetration, non-contact, low energy level, etc\cite{4,5,6}, established the thickness measuring method. The static off-line tests of tire film and wire cord fabric samples were carried out by using the T-Ray 5000 terahertz detector of API Company, USA, to verify the feasibility of THz technology test the thickness of tire wire cord fabric and the thickness of steel cord coating.

2. Test Requirements

Tire film contains single-layer, double-layer and multi-layer. The thickness of total and each layer will be measured in the experiment. Accuracy requirements are shown in Table 1.

<table>
<thead>
<tr>
<th>Index</th>
<th>Resolution ratio</th>
<th>Measuring range</th>
<th>Tolerance</th>
<th>Standard deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness $\delta$/mm</td>
<td>0.01</td>
<td>0.5-8</td>
<td>0.05</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Steel cord fabric is made of wire cord and two layers of film. It is the skeleton material in radial tire. It protects rubber and resists tension.

![coating thickness($\delta_1$) thickness($\delta$) wire diameter(d)](image)

Figure 1. Section and test items of steel cord fabric.

The total thickness($\delta$) of steel cord fabric, costing thickness ($\delta_1$) and costing thickness ($\delta_2$) will be measured. Accuracy requirements are shown in Table 2.
Table 2. Testing requirements for steel cord fabric.

<table>
<thead>
<tr>
<th>Index</th>
<th>Resolution ratio</th>
<th>Measuring range</th>
<th>Tolerance</th>
<th>Standard deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness δ/mm</td>
<td>0.01</td>
<td>0.5-8</td>
<td>0.05</td>
<td>0.016</td>
</tr>
<tr>
<td>Coating thickness δ1/mm</td>
<td>0.01</td>
<td>0.5-4</td>
<td>0.05</td>
<td>0.016</td>
</tr>
<tr>
<td>Coating thickness δ2/mm</td>
<td>0.01</td>
<td>0.5-4</td>
<td>0.05</td>
<td>0.016</td>
</tr>
<tr>
<td>Wire diameter d/mm</td>
<td>0.01</td>
<td>0.5-5</td>
<td>0.05</td>
<td>0.016</td>
</tr>
</tbody>
</table>

3. Measurement principle and methods

The test principle was the THz reflection and refraction characteristics, the detection principle of tire film and steel cord fabric was shown in the figure 2 and figure 3. The thickness of the sample was obtained by the receipt time of terahertz reflection wave and the refractive index of each layer. The formula (1) can be used to calculate.

\[
\delta = \frac{\Delta T}{2} \times \frac{0.29979}{RI}
\]  

Here \(\delta\) is the thickness, \(\Delta T\) is time difference between adjacent peak of signals, \(RI\) is the refractive index.

4. Test instruments and samples

The experiment adopts API T-Ray 5000 series terahertz system. The test samples are single-layer film, double-layer film and steel cord fabric, among which the steel wire diameter is 0.5 mm.
5. Data acquisition and analysis

The test includes single-point and line area detection. The characteristic of tire film and steel cord fabric in terahertz spectrum can be judged by single point detection. Line area detection can confirm whether terahertz is capable of quality testing during tire production process.

5.1 Single-point detection

Any point of the single-layer and double-layer tire film sample was tested. The reflection waveform was shown in figure 6 and figure 7. Abscissa denotes time and ordinate denotes amplitude.

It can be seen that there are obvious peaks and troughs, which respectively represent terahertz reflection wave of the upper and bottom surface of the tire film in figure 6. Similarly, due to the different material property of the two layers of the film, the terahertz reflection wave will fluctuate at the upper and lower layers of the film in figure 6(b).

![Single-layer tire film](image1) ![Double-layer tire film](image2) ![Steel cord fabric](image3)

**Figure 5. Picture of samples.**

![Single-layer](image4) ![Double-layer](image5)

**Figure 6. Single-point detection (tire film).**

Same operation was done in the test of steel cord fabric. The obvious difference is that steel wires produce reflected waves.

![Waveform](image6)

**Figure 7. Single-point detection (steel cord fabric).**
5.2 Line area detection

Through the single point test, the terahertz wave can pass through the tire film and steel cord fabric and receive the reflection wave. The reflection wave of different layers will show wave crest and trough. Therefore, we can use this characteristic of terahertz wave to measure the thickness of the tire film and steel cord fabric. Based on single-point detection, the samples’ line area were tested. In this paper, the test result of double-layer film is taken as example.

Figure 8 shows the line area testing waveform of the double-layer film. The three-section of waveform from top to bottom are the upper film thickness of terahertz reflection wave, the lower film thickness of terahertz reflection wave and the total film thickness of reflection wave. In this figure can obtain the thickness of each layer and standard deviations. Figure 9 is the script of thickness calculate. The refractive index of the upper film (Layer1RI) and the bottom film (Layer2RI) can be gotten. Besides, receive time of reflected waves of each layer can be gotten too.

Line area detection information of double-layer film is listed in table 3.

<table>
<thead>
<tr>
<th></th>
<th>Refractive index</th>
<th>$\Delta T$ (ps)</th>
<th>Thickness (mm)</th>
<th>Std Dev (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>2.84</td>
<td>22.58</td>
<td>1.18520</td>
<td>0.00942</td>
</tr>
<tr>
<td>Lower</td>
<td>2.50</td>
<td>125.90</td>
<td>7.54516</td>
<td>0.02687</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>148.48</td>
<td>8.73036</td>
<td>0.02509</td>
</tr>
</tbody>
</table>
It can be seen from table 3 that the thickness and standard deviation of the double-layer film detection data meet the resolution ratio 0.01mm and standard deviation 0.016mm in table 1. Test results are ideal. Line area detections of single-layer tire film and steel cord fabric also had done, and the results meet the test requirement as well.

6. Summery

The experimental research on single-spot detection and line area detection proves that the reflected waves with obvious characteristics in terahertz band for tire film and steel cord fabric, and thickness can be measured by terahertz wave, the results can meet the requirements of industrial production. With its high stability and reliability. The detection of line area provides theoretical basis for THz wave measurement of tire semi-finished extrusion components.

7. Acknowledgement

This research was financially supported by Qingdao Basic Application Research Project (Grant No. 17-1-1-93-jch), Qingdao Science and Technology Innovation Platform Construction Project of (Grant No.17-6-3-18-gx) and Weihai science and technology development project (Grant No. 2016GGX022).

References