Optical System for Detecting Creases in Polyethylene Sheets

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An optical system for detecting creases has been developed. The system consists of a movable sensor head with a pulsed semiconductor laser of 10 kHz and a silicon photodiodes, an analog data processing system including an amplifier with a band-pass-filter, a rectifier and an integrated circuit, and a digital data processing system including an 8 bit A/D converter with a sampling frequency of 1 kHz, a personal computer, and an alarm for crease detection. The detection capability for creases with widths of 2 mm and lengths longer than 3 m was above 95% for manufacturing plants with production conditions of 1 m/s and sheets with widths of 1 m.

Key Words: Optical detection system, Creases, Polyethylene sheets

1. Introduction

Polyethylene sheets have been used mainly in batteries. The main functions of these sheets are to insulate the electrode, impregnate sulfuric acid, and pass air bubbles during the process of electrolysis. The ribs on the sheet act mainly as an insulator, and the sheets' porosity acts as an impregnator and an air filter. Thus, a battery's performance is determined mainly by the rib's and sheets' porosity. The degree of porosity is determined by the amount of oils impregnated in the early state of manufacturing, which is finally extracted resulting in porosity.

Ribs are formed by means of a metal mold after the oil has been extracted. The size and separation of the ribs are important factors in the performance of the battery. We have reported an optical system for measuring these factors away from the manufacturing line, i.e., in off-line. Polyethylene sheets with widths of about 1 m and a thickness of about 0.3 mm have usually been manufactured by means of an extruding machine at a considerably high speed of about 1 m/sec. In such high-speed manufacturing, crumbling, creasing, and the deformation of ribs occur at times, resulting in inferior goods. This constitutes a rather serious problem for a manufacturer.

Some optical methods have been developed for inspecting the surface of industrial parts and evaluating their surface roughness. These methods using a scattered light can, in a principle, be used for detecting creases in a polyethylene sheet. However, in this study scattered light is used to detect the creases in the sheet since creases drastically alter the shape of scattered light.

Figure 1 shows some samples of a polyethylene sheet containing creases. These are cut samples used practically in batteries. A sheet of about 1 m in width was produced at a production speed of about 1 m/s in a plant. Once these creases have developed in a sheet, the flaw continues to be imposed on the sheet due to the high production speed. A length of a crease is over 3 m, with a width of usually a few mm. The purpose of this study is to develop an optical system for detecting these creases.

2. Method and system

In our previous paper, transmitted light was used to measure the rib size and the separation between them formed on the polyethylene sheet. However, in this study scattered light is used to detect the creases in the sheet since creases drastically alter the shape of scattered light.

![Fig.1 Some samples of polyethylene sheets. (a) and (b); interior side with ribs, and (a') and (b'); exterior side without ribs.](image-url)
while the product is being manufactured, i.e., in-line. As is shown, the creases appear on both sides of the sheet, i.e., the interior side with the ribs (Figs. 1 (a) and (b)) and on the rough flat exterior side (Figs. 1 (a') and (b')). Thus, the creases can be detected by means of the scattered light directed onto the flat exterior side since the scattered light on the interior side becomes rather noisy due to the ribs. Both scattered and reflected lights can be used to detect the creases as in the previous study. Scattered light was, however, used in this paper from the following reasons. One is that reflected light was more noisy due to ribs than scattered light; reflected light changed largely on even an undulated surface due to the ribs, resulting in a light noise. Another is that an intensity change in scattered light due to creases, i.e., a signal, was larger than that of reflected light. Thus, scattered light has a greater S/N ratio than that of reflected light.

Figure 2 shows the optics for the detection of creases. Laser light with a wavelength of 670 nm from a semiconductor laser irradiates a polyethylene (PE) sheet vertically. A sheet-like laser light of 1 mm x 10 mm was irradiated on to the sheet parallel to the production direction, i.e., lengthwise with the creases, to increase a change of scattered light intensity due to creases, i.e., a signal. A long narrow photodiode of 1.2 mm x 15 mm was used according to the sheet-like laser light. A part of the scattered light was received on this photodiode resulting in a signal. The output of the receiver is linearly proportional to received light intensities within a wide range of intensity. The light receiver was fixed at about 8 mm from the irradiated portion and at a horizontal angle of about 20 degrees. These optical conditions including laser irradiation and the light receiver were found to be the best choice as based on experiments involving various irradiated sizes and forms, and distances and angles of the receiver. The width of the sheet-like laser, 1 mm in this case, was about half of the smallest width of the creases. This condition was similar to the optimum conclusion for detecting surface flaws determined in a previous study. The laser traces a zigzag course on the polyethylene sheets as shown in this figure since both the polyethylene sheets and the laser move perpendicular to each other.

Figure 3 shows the block diagram of the system. The amplifier with a band pass filter amplifies the output on the silicon photodiode and transmits only the output of a pulsed laser to an A/D converter. An amplified analog signal from the amplifier is converted to digital signal by means of an 8 bit A/D converter. The digitized signal is, then, received on personal computer (PC), where the signal is processed to detect and correct for creases. The PC also gives a warning signal for the detection of creases and a driving signal for a stepping motor to move the laser. The sampling frequency of the system, f, was f = 1 kHz.

3. Results and discussions

A preliminary experiment was performed to determine the accuracy of the proposed method. Figure 4 shows the experimental setup used in this study. The laser was scanned transversely going and returning, i.e., direction of width (W), with a speed of \( v = 0.05 \text{ m/s} \). The speed of the PE sheet, V, was about 0.4 m/s in this experiment. The ratio of the scanning speed of the laser to the speed of the PE sheet, \( v/V \), should be chosen properly since an irradiated area traces a zigzag course on the PE sheet as shown in Fig. 2; short creases cannot be detected. To detect all the creases with a length longer than L, the following relation is required since \( L \) should be longer than \( VT \), where \( T \) is the turnaround time of the laser between the sheets, i.e., \( T = 2W/v \).

\[
v > 2W/L.
\]

(1)

In a practical plant, almost all creases are longer than 3m. Thus a laser scanning speed of \( (2/3) \text{ m/s} \) is necessary for a production speed of \( V = 1 \text{ m/s} \) and a PE sheet width of \( W = 1 \text{ m} \).

Figure 5 shows an example of the received signal. The large change is due to creases, which is used as a signal. On the other hand, the small change is due to ribs on the interior side, which is a noise. Thus, the creases can be detected clearly at a glance since the signal is greater by 5 times than the noise. That is, the
Fig. 5. An example of the received signal. Each dot represents a mean value of 10 samples.

latest peak-to-peak value obtained at successive intervals, i.e., a new value, was compared with the mean value over 100 peak-to-peak values just before a new value; an alarm signal for creases was displayed when the new value was greater by 2.5 times than the mean values. A value of 2.5 was a best choice for our purpose; the accuracy of detection was above 95% for this value, and was lower for other values of 2.5. That is, some creases were missed at greater values than 2.5, and the excessive creases due to noise were over-detected for values smaller than 2.5.

Each datum, i.e., the dots in Fig. 5, was a mean value of 10 samples, which decreased an abrupt change of the light intensity of each sample mainly due to a surface condition of the sheet. This means that the effective sampling frequency, \( F \), is only \( F = 100 \ (= f/10) \) Hz. The degree of this smoothing, \( n = 10 \) in this experiment, should be so chosen that an effective sampling should be performed on every crease when a laser scans sheets with a velocity of \( v \). This leads the following condition for a width of creases, \( w \), since a period of effective sampling is \( 1/F \):

\[
v < Fw = \left(\frac{f}{n}\right)w
\]

In this preliminary experiment, the scanning speed of \( v = 50 \) mm/s is small sufficiently compared to the value of \( Fw = 200 \) mm/s for \( w = 2 \) mm. Creases were, then, detected clearly as shown in this figure. Considering these two conditions for \( v \) given by Eqs. (1) and (2), the following condition for the sampling frequency can be given.

\[
f > 2Wn/(Lw)
\]

Thus, an A/D converter with a sampling frequency of above 3.3 kHz is required for a manufacturing plant with production conditions that include \( W = 1 \) m, \( V = 1 \) m/s, \( n = 10 \), \( L = 3 \) m, and \( w = 2 \times 10^{-3} \) m.

4. Conclusion

An optical system for detecting creases in polyethylene sheets in real time has been developed. The system consists of a sensor head with a semiconductor laser and a line photodiode, a signal processing system including an amplifier with a band pass filter, an A/D converter, a personal computer, and an alarm. It was found from the preliminary experiment that an A/D converter with a sampling frequency of 4 kHz was adequate for a plant with production speed of 1 m/s and sheets with widths of 1 m, and that the accuracy of this system for creases of longer than 3 m and greater than 2 mm in width was above 95%. The system is now used in a plant.

References