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Detection of foreign bodies in canned foods using ultrasonic testing

*Meftah, H. and Mohd Azimin, E.

Department of Mechanical Engineering, International Islamic University Malaysia, P.O. Box 10, 50728 Kuala Lumpur, Malaysia

Abstract: Foreign bodies in packaged foods may pose both a safety risk and a risk of perceived degradation of quality. When food products are manufactured or packaged, small foreign objects might end up in the product. It is naturally desirable for the food industry that all foreign bodies are detected and removed before they reach customers. In this study, the ultrasonic method was used to detect the foreign bodies in canned foods. In order to establish a technical concept for the detection of foreign bodies in canned foods, an experimental investigation was carried out using pulse-echo ultrasonic testing. A number of simulated foreign object pieces were deliberately put inside the canned food and the results were analyzed. The approach demonstrates that ultrasound has potential for application in many industrial food packaging environments where foreign objects need to be detected. Indeed, detection up to 4 millimeter foreign body size has been done for rock and metal foreign bodies.

Keywords: Canned food, foreign bodies, nondestructive testing, ultrasonic

Introduction

A foreign body (FB) is defined as a piece of undesirable solid matter present in a product. The food manufacturer's objective is to supply products completely free from foreign bodies, in order to meet the consumers' expectations (Wallin and Haycock, 1998). It has been considered a serious offense for food manufacturers to carelessly fail to detect the presence of the foreign body inside their food products. The economic justification for addressing these as serious issues arises from the need to protect a brand name, whether it's the brand of the manufacturer or of the retailer. Rather than the brand being damaged by a spate of consumer complaints, the reaction is usually to recall the product that might be affected. If the foreign body and its source can be identified and traced to a source in the supply chain, the depth and breadth of the recall can be limited (Andrews *et al.*, 2001).

Ultrasound-based measurement is a promising method for foreign body detection because it has ability to differentiate discontinuities in acoustic impedance between different regions within a given volume. Such discontinuities would represent a thing that differs from its surroundings, such as a foreign body. In addition, ultrasound is non-destructive and does not spoil foods physically or hygienically (Ginesu *et al.*, 2004).

Few research works have been carried out for detection of foreign bodies or contaminants such as bones, mineral stones, natural rubber, ferrous or non-ferrous metals, glass, etc. in the food industry. Pearson *et al.* (2001) showed the feasibility of an automated food inspection system for pistachio defect detection based on X-ray imaging and statistical characterization. Talukder *et al.* (1999) used X-ray imaging to perform nondestructive testing using feature discrimination. Casasent *et al.* (1998) obtained promising results by X-ray imaging and neural net processing to classify pistachio nuts. Pearson (1999) then used near IR transmittance to detect concealed damage in nuts. Other works deal with the problem of nondestructive quality control by infrared imaging or spectrometry (Mowat and Poole, 1997). Ultrasound has been proposed to monitor product quality at various points along the production process, and there are many publications which describe its use for measuring the properties of food (Javanaud, 1988; Povey and McClements, 1988). Air-coupled ultrasound has been described for some time (Gan *et al.*, 2002) and is often used in conjunction with some form of signal processing to increase the signal to noise ratio.

In this work, we experiment with the feasibility of pulse-echo ultrasonic nondestructive testing for the detection of different types of foreign bodies in food products. Section II gives a description of the canned food specimen and the foreign bodies. The next section deals with the experimental setup. Finally, experimental results are given and discussed in Section IV.

Materials and Methods

Canned food specimen

The specimen used in this test was an aluminum tin container filled with water (Figure 1). We artificially

*Corresponding author.
Email: *meftah@iium.edu.my*
Tel: +603 6196 4581; Fax: +603 6196 4455

introduced foreign bodies of different materials and sizes into the filled container in order to simulate FB in beverage containers or packaged sauces.

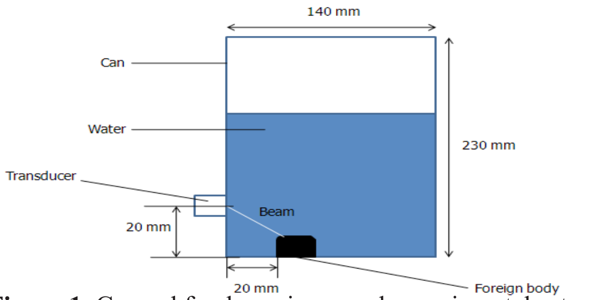


Figure 1. Canned food specimen and experimental setup

Foreign bodies

There are three types of foreign bodies that are deliberately being introduced inside the canned food specimen:*FB1*: a rock of dimension 62 x 38 mm, *FB2*: an aluminum plate of dimension 30 x 23 x 4 mm and *FB3*: an aluminum plate of dimension 122 x 21 x 1 mm. *FB1* has different density than *FB2* and *FB3,* while *FB2* and *FB3* have clearly different sizes. These different properties, i.e., the difference in densities and sizes are tested during the experiments.

Experimental setup

The experimental set-up is shown in Figure 1. The tin container has flat sides of 1 mm thickness and was filled with water. An ultrasonic transducer (PHOENIX A2650, diameter 10”) is mounted to the side of the canned food specimen. The transducer used was a flat-focused ultrasonic transducer of nominal frequency (4 MHz). Oil was used to couple the ultrasonic pulse to the specimen. A TD Scan Advanced Ultrasonic Inspection System was used to drive the transducer and to receive the echo signal. The result was displayed on the TD Scan monitor in real time.

NDT instrumentation

Ultrasonic testing requires an ultrasonic pulser-receiver, a transducer and a data display. In the experiment, a 4 MHz, 45^o incidence angle beam transducer was used for FB detection by evaluating the A- Scan display of ultrasonic propagation. Oil was used as the couplant.

The setups were done as in Figure 2. The foreign body, i.e., the rock and the aluminum plates, were deliberately positioned inside the can, which was filled with water to a relatively constant level. The position of the foreign body inside the can was calculated manually. The calculation was based directly on the Snell’s law which describes the relationship between the angles and the velocities of the waves. Snell’s law equates the ratio of material velocities V_{L1} and V_{L2} to the ratio of the sines of incident (θ_1) and refracted (θ_2) angles, as shown in the following equation:

$$\frac{\sin\theta_1}{V_{L_1}} = \frac{\sin\theta_2}{V_{L_2}} \tag{1}$$

Using equation (1) with the velocity of ultrasound in the transducer wedge (V_{L1} = 6,300 m/s), the velocity of ultrasound in tin (V_{L2} = 5,960 m/s), and θ_1 given by the 45˚ angle beam from the transducer, one can calculate the value of θ_2 –known as the longitudinal wave angle- to be 45˚.

Using the Pythagorean theorem of triangles, when the transducer is positioned at the wall at 20 mm from the bottom of the can, it should detect any foreign body positioned at around 20 mm from the particular wall, as described in Figure 1.

Different scenarios have been experimented: *Experiment 1*: the tin can was half full of water without foreign bodies, *Experiment 2*: FB1 (rock) was positioned in the can, *Experiment 3*: addition of FB2 (thick aluminum plate) and *Experiment 4*: addition of FB 3 (thin aluminum plate).

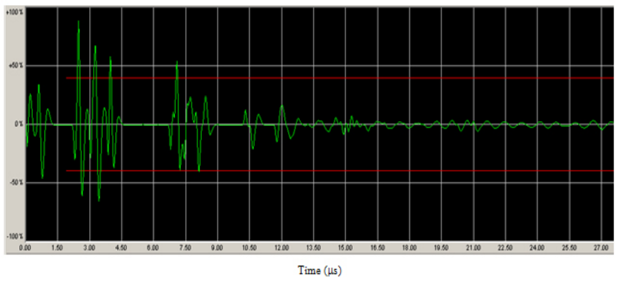


Figure 2. Real time signal for a ‘no FB’ experiment

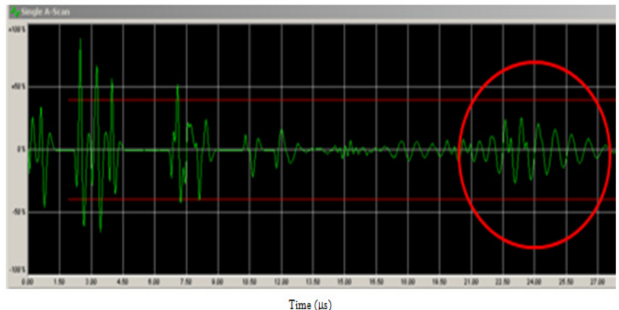
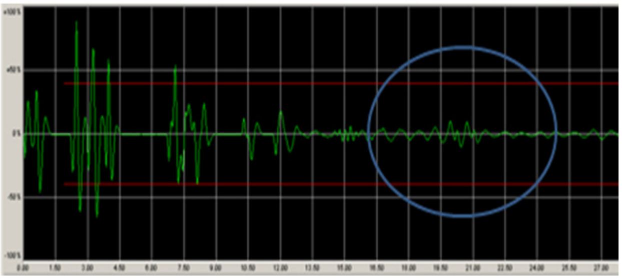


Figure 3. Real time signal for a ‘with FB1’ experiment

Results and Discussion

Figure 4 is a typical signal sampled in the absence of FB in the container. It shows the real time signal in which two echoes from the outer and inner surfaces are observed. They are overlapped to some extent due to the short round trip time of the ultrasound in the thin side of the container. Notice that there are no more apparent echoes after the one from the inner surface which means that there is no other presence except water inside the can.



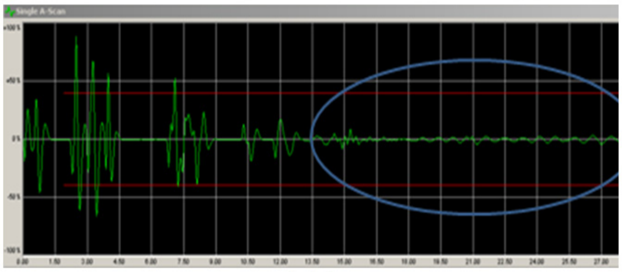
Time (μs)

Figure 4. Real time signal for a 'with FB2' experiment

Consequently, from the graphs obtained from the experiment, the calculation of the depth or location of foreign bodies in canned food can be determined. The calculation of the depth using pulse-echo ultrasonic testing is achieved by equation (2). Note that from Figure 4, the thickness of the wall of the can, *d*, could easily be determined by referring to the x-axis of the graph, which is the echo trip time, *t* (μs). From peak-to-peak of the wall's echoes, the thickness of the food container can be evaluated as 1 mm using the following equation:

$$d = \frac{V\,t}{2} \qquad (2)$$

Figure 5 corresponds to the second experiment. The first three echoes in Figure 5 indicate the same echoes as in Figure 4. An obvious additional echo is circled in red. Note that this particular echo started at the position of 22 mm from the transducer. Clearly, the signal indicates the presence of FB1, the rock.



Time (μs)

Figure 5. Real time signal for a 'with FB3' experiment

The signal obtained from the experiment with FB2 is shown in Figure 6. When compared with the reference signal of the experiment without FB (Figure 4), the 4 mm-thick aluminum FB can still be detected by the transducer with slight echo in the graph that occurs at around 19 mm from the transducer position.

Recall that in experiment 4, a thin plate of aluminum (1 mm thick) has been added as the foreign body in the can. Compared to the reference experiment 1 result (Figure 4), Figure 7 indicates no obvious echo which lets us assume that the size of FB is below the sensitivity of this experimental setup and hence FB3 cannot be detected.

For these results, it is important to note that the small variations in the position of the foreign body's echo in the results do not necessarily indicate real errors of the ultrasound evaluation of the FB locations. Variations in position were primarily caused by the experimental setup itself. As mentioned earlier, the foreign bodies were positioned around 20 mm from the wall in the water. The foreign bodies are dropped approximately at the 20 mm-position. The dropping inside the water may cause the foreign body to deviate from initial drop line, thus resulting in variations in the actual position of the foreign body.

Ultrasonic inspection of foreign bodies in the alimentary industry is frequently performed in pulse echo mode (Miralles *et al.*, 2006) (similar to a radar or sonar navigation system). When an ultrasound is transmitted to a clear portion, an echo signal from the back surface of the part can be received. When a small flaw (or foreign body) is on the path of the ultrasound beam, echo signals will appear ahead of the back surface echo in the time domain and the back surface echo will disappear if the flaw is large enough to intercept most of the beam from the transducer. Signals recorded this way are time-varying signals called A-Scan. There are some situations where the flaw echoes or even back wall echoes are difficult to see in the time domain. This normally appears on highly attenuating and/or non homogeneous materials. There are two effects that affect A-Scan from the signal processing point of view: Selective attenuation of higher frequencies. High spectral contents tend to disappear as time increases, and A-Scans are contaminated with structural grain noise (due to scattering in non-homogeneous materials). Some alimentary industry products present heterogeneous food texture that produces multiple reflections giving as a result noisy A-Scans.

The obtained experimental results show good detection performance for foreign bodies larger than 4 mm. Detection capability is strong related to acoustic impedance of the foreign body. Due to this, substances with similar acoustic impedance to the food product will give the worst detection results. Unfortunately, this transducer probe is of limited use for an industrial application, transducer element size is 10 mm in diameter so we are inspecting a very small part of the container. We can either choose to use an electronic/mechanical scanning system or move to a lower frequency transducer with a larger element size.

An alternative approach for identifying the presence or absence of a FB could be based on signal processing. The principle is to examine the pressure ratio between two echoes; echo P1 from the outer surface of container and echo P2 from the inner surface. The amplitude of P2 depends on the impedance relationship between the water and the container material. In presence of FB, P2 will be different from that of "no FB" due to the change of impedance. However, in practice the amplitude of P2 can change not only because of the presence of FB but also because of the gap between the transducer and the container (bad couplant) or the incident angle of ultrasound from the transducer to the container side, which can vary due to uncertainties in the scanning method. The latter could lead to false warnings in inspection. To eliminate the false warnings, P2/P1 should be calculated since the pressure ratio is not affected by the above interferences. The calculation of P2 and P1 is easy in the case of a container with thick sides, since the two echoes are clearly separated in time. In the case of thin bottom containers, the two echoes could overlap in time. In this case, time frequency method should be used in signal processing, which allows distinguishing two closely spaced echoes (Jiang *et al.*, 2003).

Conclusion

The results show the viability of an inspection system based on ultrasound energy for foreign body detection in the alimentary industry. The transducer and the setup can detect foreign bodies inside a canned food container. However, a foreign body of 1 mm thickness cannot be detected according to the above setup. Performance of the FB detection system strongly depends on the very specific acoustic impedance of the foreign body and the alimentary product we are working with. In case of beverages, detection up to 4 millimeter foreign body size has been done for rock and metal FB. Some future work that should be done: Study the possible effects that irregularities on the food container will have on the final performance of the inspection system, develop an automation system for on line inspection and work on how to avoid blind zones due to multiple echoes on front surface of the container.

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