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Food Package Inspection by Ultrasonic Imaging

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More and more food products are being packaged in flexible containers. This includes microwaveable consumer entrees, home meal solutions, fresh-prepared, ready-to-eat foods, and most notably military Meal, Ready to Eat (MRE) rations in retort pouches or thermoformed plastic trays. These types of food packages have proven themselves from the standpoint of shorter processing time to achieve commercial sterility, lower energy and material costs, and better product quality because of reduced overcooking.

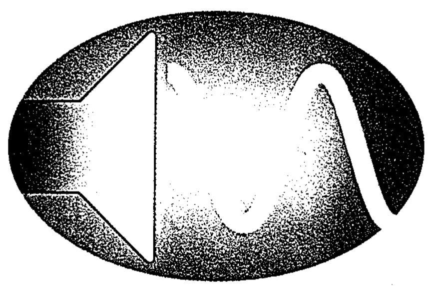
Needed: A Nondestructive Food Package Inspection Method

Container integrity evaluation is well understood for traditional cans and glass containers, but it is still a major challenge for flexible food packages. The food processing industry commonly uses destructive testing, such as burst testing, to perform spot checks of materials and sealing equipment. However, destructive testing is slow and expensive due to personnel costs and product loss. Moreover, it only provides statistical assurance, which does not guarantee the safety of untested packages. Manual or visual inspection has high personnel costs, suffers from unpredictable variation, and is unable to detect surface artifacts smaller than approximately 50μm. In summary, these packages can not be produced economically because of inspection costs, and current inspection techniques cannot guarantee the product safety. In order to overcome those problems, a dependable nondestructive inspection method is necessary to ensure the product safety and enable rapid detection of flexible food packages.

All currently available nondestructive methods have been evaluated for inspecting defects in the seal region of flexible containers. The result of this evaluation was that ultrasound emerged as the only practical technology which possessed the best combination of resolution, accuracy, speed, and safety required.

Ultrasonic Imaging: What Is It?

Acoustics is the science of sound and involves its production, transmission, and reception. Ultrasonics, which is a subdivision of acoustics, deals with mechanical waves at frequencies above 20 kHz, that is, above the hearing range of the average person. Ultrasonic waves are also named elastic waves because vibrations required for ultrasonic wave propagation are due to the elastic properties of the medium. Applications of ultrasonics are divided into two main categories: low-power and high-power applications. High-power applications intentionally produce waves with high energy that result in some changes in the medium of propagation exerting specific, desirable effects. These applications include medical therapy, disruption of biological cells, cleaning, machining hard materials, and welding of plastics and metals. Low-power ultrasonic applications do not result in any permanent change in the medium under evaluation. Thus, their nondestructive nature is used to detect defects (particularly in steel and other metals), obstacles, anatomical structure, material properties, and flow.



There are two common ultrasonic techniques used for flaw detection: through-transmission and reflection techniques. In transmission techniques, separate transmitting and receiving transducers are positioned on the opposing sides of the specimen. Ultrasonic energy is propagated through the specimen, and the receiving transducer detects the transmitted energy. Because material discontinuities result in an obstacle in the path of ultrasonic waves through which they can penetrate only partially, the amplitude of the transmitted beam decreases. Any defect getting into the path of the ultrasound beam will bring about an "acoustic shadow" on the receiver, resulting in a drop in, or a complete lack of received signal. In reflection (pulse-echo) techniques, when the propagated ultrasonic energy strikes inhomogeneities and flaws in the specimen, part of this energy is reflected. The reflected defect signal appears between the signals received from the top and bottom surfaces of the specimen. Pulse-echo techniques have an advantage over the transmission technique for on-line inspection purposes. Transmission techniques require access to both sides of the test piece, whereas in pulse-echo techniques the transmitting transducer may serve as both the transmitting and receiving transducer, reducing the complexity of the apparatus.

Backscattered Amplitude Integral (BAI)-Mode Imaging

The Packaging Laboratory and the Bioacoustic Research Laboratory at the University of Illinois at Urbana-Champaign have collaborated on the development of an acoustic sensing methodology. Ultrasonic, pulse-echo Backscattered Amplitude Integral (BAI)-mode imaging technique has been developed to nondestructively detect defects in the seal area of flexible food packages. In this technique, the defect region in the seal area will return a different combination of the BAI values, and these values are used to construct the image of the package seal. This technique has the capability of detecting defects such as channel leakers as small as 6μm; however, the technique is more effective for defects larger than 15μm. The method is already exceeding the reliability of human inspectors by being able to detect microscopic defects that are smaller than 50μm and buried in opaque materials. The BAI-mode imaging technique can provide the proper sensing method for the construction of an on-line, nondestructive package seal-integrity inspection device.

When this study is completed, engineering design parameters will be defined for an on-line, ultrasonic scanning technology that will allow for improved high-speed production of shelf stable foods in flexible packages that offer the best in quality and consumer utility.

Other Image Processing Strategies

In addition to the BAI-mode imaging technique, other image processing strategies, such as RFS-imaging, RFC-imaging and parametric ARX-imaging, have been developed. Some of them provide better contrast than the BAI-mode images and hence have the ability to detect microscopic defects. However, more research on these imaging techniques is needed to evaluate their robustness against the BAI-mode imaging by collecting data on a larger number of samples for a complete statistical analysis.

Maximizing Resolution

In applying nondestructive ultrasound imaging techniques, resolution must be considered along with depth of penetration. As the ultrasonic frequency (that was 17.3 MHz for all imaging applications discussed above) is increased, resolution increases and penetration decreases. If better resolution is desired, that could be achieved by increasing the ultrasonic frequency while keeping reasonable penetration depth (material thickness ~0.2–0.4mm) for detection of defects in the seal region. The apparent physical limitations are related to the types of materials. High loss materials such as paper or low-density foams would disperse too much acoustic energy to provide a reliable imaging technique, but the low-density polyolefin films were inspected quite well.

Engineering Trade-Offs

So far all tests have been conducted under quasi-static scanning conditions—*i.e.*, the ultrasonic transducer scans the package-seal that stays fixed in its position. Now, the question remains is how the high-frequency ultrasonic imaging would response to "real world" variables in materials, motion, environment, and signal interference. In an automated on-line package inspection system, dynamic variables such as speed and acceleration of the ultrasonic sensor relative to the continuous speed of the inspection line might contribute mechanical noise, which would adversely affect the quality of the received data. Researchers at the University of Illinois at Urbana-Champaign are investigating the engineering trade-offs of using the ultrasonic sensor for on-line package inspection. When this study is completed, engineering design parameters will be defined for an on-line, ultrasonic scanning technology that will allow for improved high-speed production of shelf stable foods in flexible packages that offer the best in quality and consumer utility. ◆

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