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Acoustic Inspection of Square-Section Capacitors

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When used in high-reliability applications, ceramic chip capacitors are often imaged acoustically to be excluded from production capacitors that have internal delaminations, cracks, or voids. A condition that can make internal defects in ceramic chip capacitors difficult, or impossible, to inspect through an acoustic microscope has recently been uncovered by work at Sonoscan.

The problem occurs only with capacitors whose body is square (rather than rectangular) in cross-section, and whose surfaces bear no markings that could serve to orient the capacitor. When the square capacitor is surface-mounted, the electrode plates may wind up either parallel to the surface of the printed wiring board or perpendicular to the surface. For the electrical functioning of the capacitor, the orientation makes no difference. If the capacitor has no internal damage, it will work equally well in either orientation. If the orientation of the delamination (and of the electrode plates) is horizontal, then the pulse ultrasound will easily image the defect. But if the delamination is vertical, it may act like a knife-edge that reflects very little ultrasound, as seen in Figure 1.

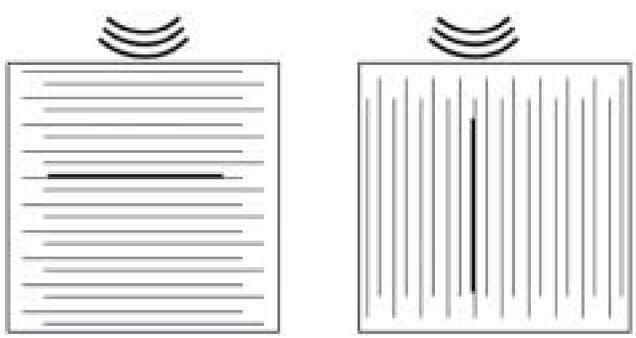

Figure 1: Diagrammatic Side View of a Square Capacitor in Cross Section with Thin Internal Delamination

When a capacitor is imaged acoustically to inspect for internal defects, the orientation of the capacitor makes a great deal of difference. Capacitors can be imaged acoustically either before or after surface-mounting, although finding and removing defective capacitors before assembly is more efficient.

Suppose a capacitor has an internal delamination between an electrode plate and the adjacent dielectric. Suppose also the capacitor is oriented for acoustic imaging with the electrode plates placed horizontally. The transducer of an acoustic microscope pulses ultrasound into the capacitor and receives the return echoes. The bulk materials of the capacitor, the electrodes and the dielectric layers, reflect very little ultrasound. But a gap, such as a horizontal delamination, is an extremely effective reflector and sends nearly all of the ultrasound back to the transducer. The thickness of the gap is unimportant since independent research has shown that any gap thicker than 0.01 micron to 0.1 micron reflects virtually all of the ultrasound that strikes it.

The highly reflective nature of delaminations and other gap-type defects, such as cracks and voids, makes them easy to find acoustically, as long as the capacitor is oriented so that the electrode plates and dielectric layers are horizontal.

But if the capacitor is rotated 90°, the electrode plates and the dielectric layers are now vertical. A flat, thin delamination between two layers is also vertical and presents, what amounts to, a very thin knife-edge to the arriving ultrasonic pulse. In this orientation, there is very little material gap that can reflect ultrasound, and the resulting acoustic image may either display the on-end delamination as a very fine line or may not display it at all.

This is the problem that square capacitors have—there is no way for the technician performing the acoustic inspection to know what the orientation of the internal feature is. The net result is that an internal defect that has the potential to degrade the capacitor over time and to cause the capacitor to fail electrically can slip right through inspection. Defects that are not truly flat, for example, with a slightly curved crack or an undulating delamination, do not present this problem. (If the cross-section of the capacitor is rectangular rather than square, then the orientation of the internal features will be obvious and there will be no question about the proper imaging method.)

Figure 2: Acoustic Image of 30 Square-Section Capacitors with Only Three Having Internal Defects (A, B, and C)

There are two ways to solve this problem. The first is shown in Figures 2 and 3, both of which show the same 30 capacitors at one corner of a much larger tray that was

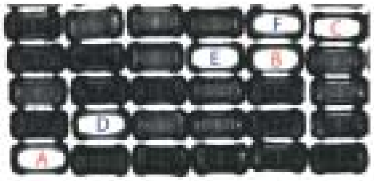

Figure 3: Acoustic Image of Same Capacitors in Figure 2, after "Dark" Capacitors Rotated 90°—Three More Capacitors Seen with Internal Defects (D, E, and F)

being imaged in order to screen out defective capacitors before surface-mounting. All of these capacitors are square in cross-section, and none has any surface markings that would tell the user whether the electrode plates inside the capacitor are horizontal or vertical, so it can be assumed that the 30 capacitors in Figure 2 have a random mixture of horizontal and vertical orientations.

Ordinarily, the pulse from the ultrasonic transducer is gated on a particular depth within the capacitor. Gating means that only those return echo signals within a defined time window (a given number of nanoseconds after the pulse is launched) will be used in making the acoustic image. Return echo signals that arrive before the prescribed time are ignored, and so are signals that arrive after the prescribed time. In some work, very narrow gating is important to separate two internal features from each other, but in routine capacitor work, where the goal is typically to identify internal defects at any depth, a wider gate is typically used. The gate extends from just below the top surface of the capacitor to just above the back surface. This technique is known as bulk-scan imaging, and is the method used in Figures 2 and 3.

Along with gating, the transducer is also focused. For capacitor work, the transducer is typically focused halfway between the top surface and the bottom surface. This focusing was used in Figures 2 and 3.

Figure 2 shows three capacitors (marked A, B, and C) have brightly reflective white defects. The other 27 capacitors, the dark ones, may have no defects, or they may just be oriented the wrong way; that is, their defects may be too vertical to be imaged.

To make Figure 3, the three defective capacitors seen in Figure 2 were left in their original orientation, and the 27 "dark" capacitors were all rotated by 90°. When the capacitors were scanned this time, three additional defective capacitors (D, E, and F) were revealed. All of the capacitors that are dark in Figure 3 have no internal defects because they have no bright reflection in either the vertical or horizontal orientation.

This method is very effective, but it involves scanning the tray of capacitors twice, and rotating most of the capacitors between the two scans. There is also a way to find razor-thin flat defects by using a single scan, and without rotating the capacitors. The single-scan method uses the Loss of Back Echo (LOBE™) technique developed at Sonoscan.

The Loss of Back Echo method gates narrowly on the back surface of the capacitor rather than on the whole thickness of the capacitor. Focusing, however, remains unchanged. The result is that return echoes from the back surface of the capacitor are collected. These echoes are the result of a pulse that has first traveled through the entire body of the capacitor, reflected off the back surface of the capacitor, and then traveled to the front surface again.

This round trip means the pulse will encounter the vertical delamination twice, which in turn means there is far more interaction between the vertical delamination and the ultrasound. The ultrasound produces an acoustic shadow of the delamination and, as a result, the delamination, even though vertical, shows up in the acoustic image.

In Figure 4, the capacitors were kept in the same orientation as in Figure 2, and the tray was then scanned using the LOBE technique. All six defective capacitors have noticeably dark internal features in Figure 4, making it easy to identify the defective parts. The three capacitors that are vertically oriented (D, E, and F in Figure 3) have strong dark horizontal lines—the acoustic shadows of the delaminations in Figure 4. This LOBE image was made simultaneously with the bulk-scan image in Figure 2.

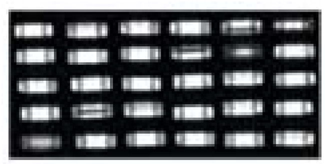

Figure 4: LOBE (Loss Of Back Echo) Image Made at Same Time as Figure 2—All Six Defective Capacitors Can Be Identified

During the screening of a large number of square-section capacitors, the technician does not need to physically rotate the parts. Ordinary bulk-scan imaging and LOBE imaging are carried out during the same scan by setting two different gates, which produces two images. Capacitors in which the delamination is oriented horizontally will be revealed in the bulk-scan image, while capacitors in which the delamination is oriented vertically will be seen in the LOBE image. All of the defective capacitors will be found in a single scan. The same simultaneous technique is used to image surface-mounted capacitors.

The techniques used for square-section capacitors work equally well for capacitors whose cross-section is nearly square. The trend toward very small capacitors makes it hard to manufacture capacitors having precise dimensions, and large numbers of small capacitors have a cross-section that is nearly, but not quite, square. Experience in acoustic imaging has shown that the technician cannot assume that the plates are parallel to the longer dimension. In many instances, they are parallel to the shorter dimension. Internal defects can still be found by using bulk-scan imaging and LOBE imaging simultaneously. ❑