# Annular array sensor design for improved structural health monitoring

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Great strides forward are being made in the utilization of ultrasonic sensors in Structural Health Monitoring. Approaches to date have focused on using off the shelf circularly shaped transducers on a structure to send and collect ultrasonic signals without any consideration of signal optimization via the physics and mechanics of wave propagation. Mode and frequency control is not possible. Analysis is based on a wave signature technique to depict signal changes as a result of damage present between the sending and receiving sensors. In practically deployed structures, the environmental interaction of the sensors can profoundly influence the measurements. For example, oil spills are a common site near oil storage tanks, and water gets accumulated on the sleepers used to hold oil pipelines. Appropriate sensor design plays a very important role in defect detection with ultrasound. By studying the underlying wave mechanics it is possible to design sensors for maximum penetration even under various unwanted external conditions and identify artifacts from a real defect. A new way of designing sensors by considering the appropriate wave mechanics to introduce ultrasonic waves with the most appropriate wave structure for inspection is studied. The sensors can also help tremendously in tackling the age old problem of classifying the kind of defect present in a structure namely surface corrosion, delamination between layers, or adhesive bonding interfacial weakness.

Comb transducers have the capability to introduce a desired wave mode with a suitable wave structure while minimizing the other modes in the structure being inspected. With comb transducers, by controlling the time delay between successive elements, it is possible to excite any desired wave structure. Two methods were employed to fabricate the sensors, (1) using PVDF films with appropriate electrodes and (2) with piezoceramic disks with the electrode pattern etched onto the surface. PVDF is a broad banded material and hence suitable to operate at different frequencies, but its low electrical to mechanical coupling makes it unsuitable for composite structures. Piezoceramic disks have a very high electrical to mechanical coupling but are very narrow banded, forcing their use to limited frequencies on different structures. The fabricated sensors from these two materials can be seen in Figure 1.

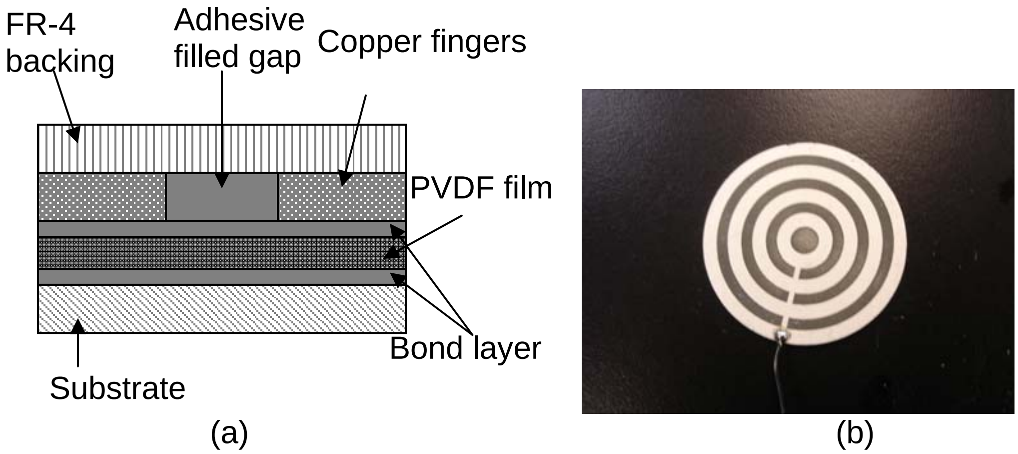



*Figure 1*. (a) Electrode pattern bonded onto a PVDF film (b) Electrode pattern etched on a piezo ceramic disk.

Identifying the wavelength and wave mode is a complicated task considering that there are infinite possibilities for exciting a wave mode most suitable for inspection at a particular frequency and phase velocity. Theoretical understanding of the problem at hand can reduce the possibilities to a finite set. We can arrive at a suitable point in the dispersion space of the structure for defect identification by considering the type of defect we want to detect and the best possible wave structure for its identification.

A false alarm due to water loading is a common problem encountered in inspecting structures deployed for use. By intelligently designing a sensor that can overlook the presence of water, it is possible to reduce the false alarm rate. From theoretical calculations it is possible to determine the wave structures that exhibit minimal sensitivity to water loading on a structure. For a thin aluminum plate of thickness 1.6 mm it is found that at 2.4 MHz a point on the dispersion curve has dominant in plane particle vibration, hence no energy leaks into the water. Sensors using PVDF films are designed at this point and tested on the structure. It can be noticed from Figure 2 that at 2.4 MHz it is possible to separate real defects from a false alarm.

Bond degradation in composite structures is a very important problem in aerospace structures where a majority of the structure is made of composites. Adhesive bonds are also commonly used to bond two different metals. It is possible to design sensors that can be sensitive to defect presence only in the adhesive bond of the structure. For two aluminum plates each of thickness 1.6 mm bonded together by a 0.2 mm epoxy bond we can select points on the dispersion curves that can focus energy at the bond interface. Figure 3 shows the appropriate point and its wave structure with the energy concentrated at the interface.

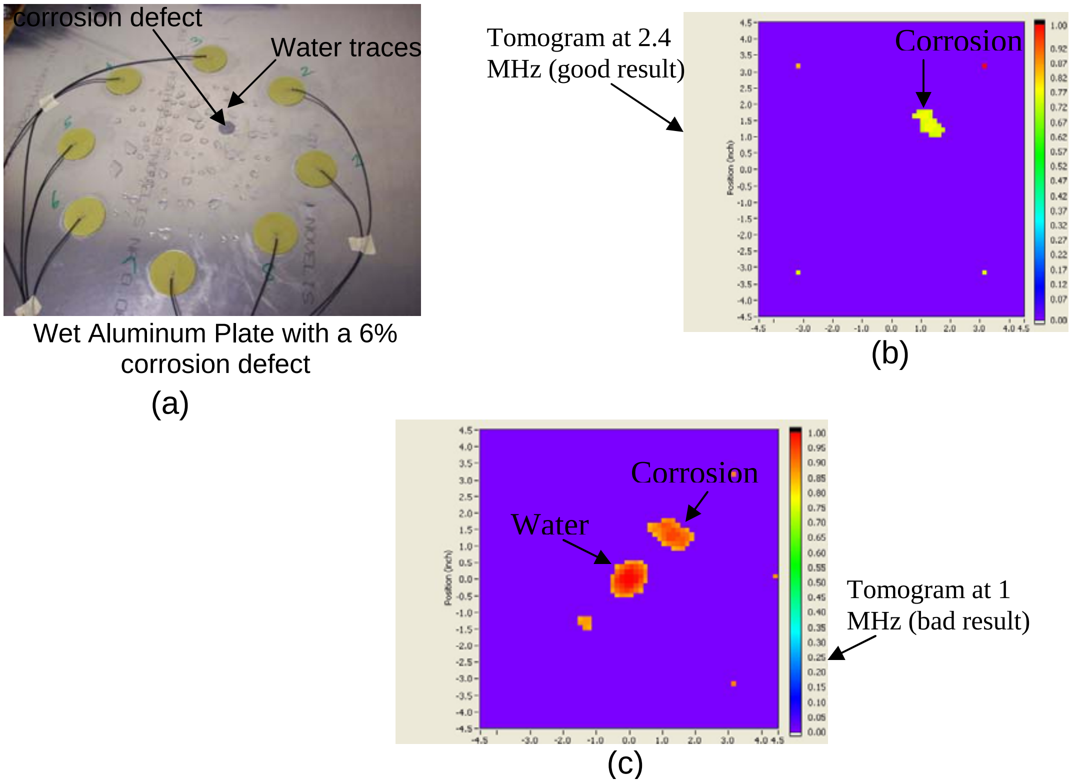



*Figure 2*. (a) Aluminum plate of thickness 1.6 mm being inspected by 8 sensors (b) Tomogram of the structure at 2.4 MHz showing a good result (c) Tomogram at 1MHz showing a bad result because an incorrect mode-frequency pair was chosen.

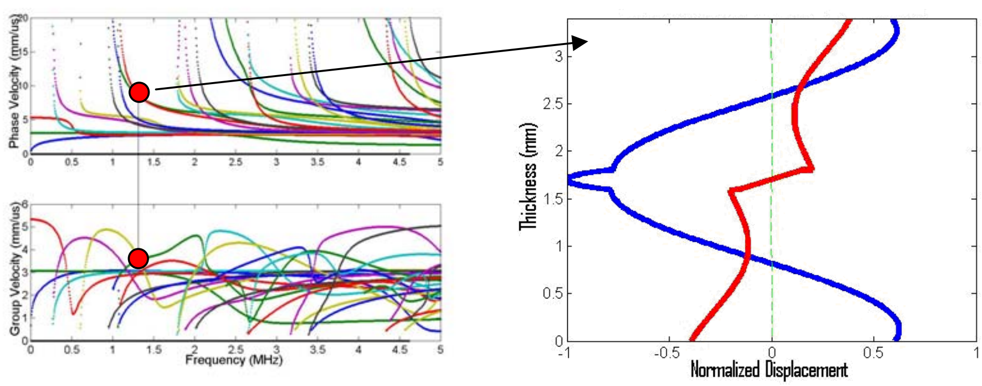
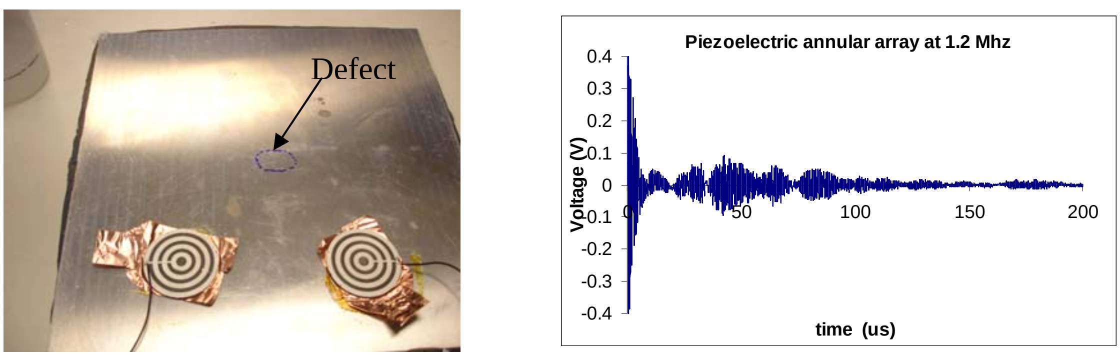


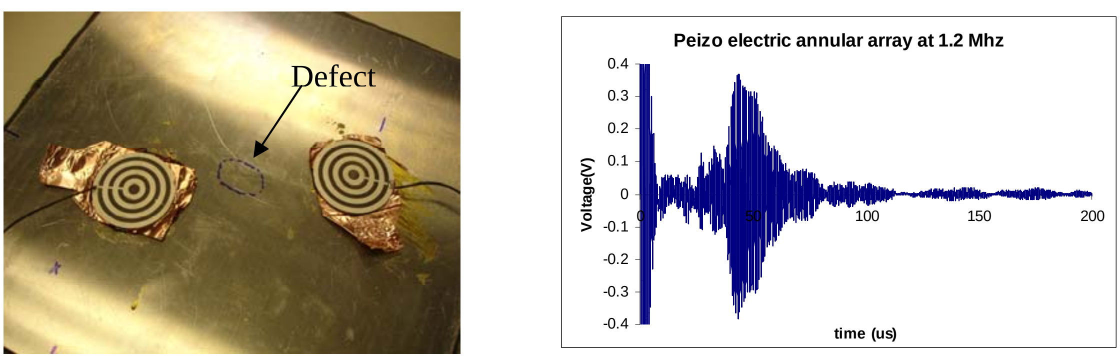

*Figure 3*. Phase velocity and group velocity dispersion curves for an aluminum-epoxy-aluminum bonded plate, with the wave structure at one mode at 1.2 MHz concentrating its energy at the interface.

Being a composite structure, the PVDF sensor cannot achieve the desired penetration, hence piezo ceramic sensors are used with the electrode pattern etched onto the silver electrode deposited on the sensors. The debonding or weak interface in a bonded structure can be simulated by introducing Teflon inserts while bonding the metals. A sample is prepared by introducing a Teflon insert, as can be seen in Figure 4, that the sensors can clearly identify a defective region from the non-defective region.

Structural heath monitoring applications often introduce unique problems, most of which can be addressed by an understanding of the underlying wave mechanics and appropriate sensor design. Two laboratory problems were studied here, namely overcoming false alarms from water loading in deployed structures and identifying bond weakness in bonded plates that are solved by designing suitable sensors that can address them. It is also possible to introduce electronic time delays between the fingers of the comb sensor making it possible to excite any point on the dispersion curve space hence providing sensitivity and penetration power modifications to a variety of different defects in establishing appropriate reflection and through transmission wave resonances.




(a)




(b)

*Figure 4*. (a) Sensors collecting data in region with no defect and its corresponding signal at 1.2 Mhz (b) Sensors collecting data near the defective region and its signal.