Piezocomposite technology
An innovative approach to the improvement of N.D.T. performance using ultrasounds

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Abstract

The ever-increasing need for improved performance and adaptation to particular inspection conditions calls for the development of new ultrasound sensor technologies, such as Piezocomposite 1-3 technology.
This technology makes use of piezoelectric elements in the form of composites made up of ceramic micro-rods embedded in a polymer matrix.
This article will describe the structure of these piezocomposite materials and their most important electroacoustic and mechanical characteristics.
A certain number of applications that can benefit from this technology will also be presented. These applications make use of a large number of different types of sensors in the 200 kHz to 20 MHz frequency range, in particular immersion sensors with high electroacoustic performance (sensitivity, signal / noise ratio, damping), focused sensors with very high lateral resolution, high temperature sensors, and multi-element or phased array sensors.

Introduction

The growing needs of Non-Destructive Testing by ultrasounds to reduce untested areas, improve the speed of inspection and increase detection and sizing performance, have resulted in recent years in the development of advanced sensor technologies, such as phased array sensors and Fermat sensors (with aspherical focusing).
These latest generations of sensors use the key Piezocomposite 1-3 technology to achieve their acoustic component.
The electroacoustic performance of these piezoelectric materials, combined with their mechanical properties, have enabled improvements to be made in many inspections and new inspections to be made that were not possible using sensors with a monolithic piezoelectric element.

Piezocomposite materials

The 1-3 Structure

Imasonic's piezocomposite materials have a structure called 1-3, shown in figure 1. The piezoelectric ceramic rods are inserted in a polymer material. The ceramic and the resin are chosen according to the characteristics required for the composite material. The geometry of the microstructure itself can be adapted.

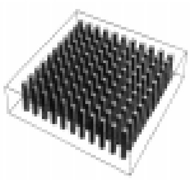

Figure 1 : schematic representation of 1-3 Piezocomposite structure

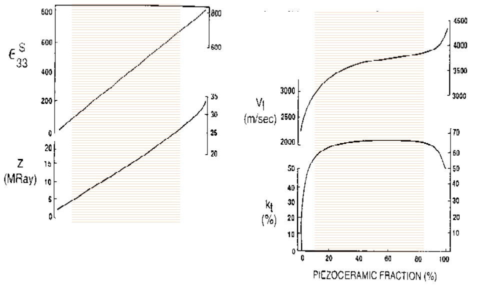

Figure 2 : Influence of the percentage of ceramic on the performance of Piezocomposite materials

Adjusting the percentage of ceramic

One of the characteristics of the 1-3 structure is that the percentage of ceramic can be varied by modifying the size of the rods and their spacing. Figure 2 shows the influence of the percentage of ceramic on the performances of the piezocomposite which are:

- The coupling coefficient kt on which the sensitivity of the sensor depends
- The dielectric constant $\in_{33}$ on which the electrical impedance depends
- The acoustic impedance Z
- The Velocity of propagation in the material on which the frequency for a given thickness depends

A higher or lower percentage of ceramic also gives different mechanical properties to the composite material

Electroacoustic performance

The height of the ceramic rods, long compared to their lateral dimensions, favours their vibration according to the thickness mode to the detriment of the radial mode. This results in improved electroacoustic efficiency which gives the sensor a high level of sensitivity, and a high signal / noise ratio. In addition, the natural damping of composite materials allows a relative bandwidth of 60% to 90% to be obtained while retaining a very good level of sensitivity.

Mechanical properties

The polymer's mechanical properties are used to enable the piezocomposite materials to be shaped for focused transducers. Figure 3 shows a wide-aperture sensor, whose active area is given a convex shape in order to focus through the cylindrical interface of a bore.
The 1-3 structure also gives composites better resistance to mechanical shocks and vibrations.
The expansion coefficients of the polymer being close to those of the other constituents of the transducer (front face, damper, etc), results in the sensor having an improved performance in terms of temperature and thermal shock.

Figure 3 : Example of a wide aperture probe (100mm) with shaping of the active area

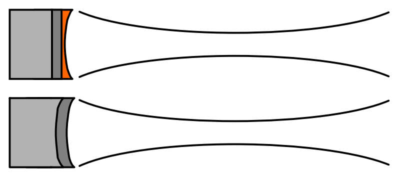

Figure 4 : Comparison between focusing with a lens and focusing with shaping of the active area

Immersion probes

Acoustic adaptation to water

The acoustic impedance of piezocomposite materials can vary, to the order of 11MR on average. This impedance, much smaller than that of ceramics, is much closer to that of water. This results in a better transfer of energy which, combined with a strong electroacoustic performance, gives a level of sensitivity from 10 to 50dB greater than that obtained with monolithic piezoelectric ceramics.

Focusing by shaping

The shaping of the active area, illustrated in figure 4, enables a beam to be focused without using a lens that dims and deforms the beam.

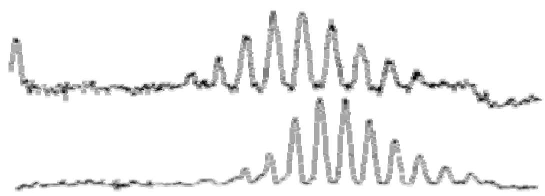

Figure 5 : Comparison between
A piezo-ceramic sensor with focusing lens: noise to signal ratio 20 dB – lateral resolution 6.5 mm
A piezocomposite sensor with aspherical focusing: noise to signal ratio 38 dB – lateral resolution 4.5 mm

Aspherical focusing

Aspherical focusing of the active area enables a sensor to focus on a precise point in the heart of the material, with a given refraction angle, and through an interface of a given geometry. Each point of the active area is situated at an identical time-of-flight from the focusing point and is generally combined with a wide aperture to produce sensors with a very high lateral resolution and signal/noise ratio. A comparison is shown in figure 5.

High temperature probes

As shown in the preceding paragraphs, the mechanical properties of piezocomposite materials allow improved resistance to temperature and to temperature variations. Some examples can be given:

- Measurement of flow in a liquid metal up to 250°C (480°F)
- Detection of ice on airplane wings from –55°C (-67°F) to +85°C (+185°F) with rapid variations
- Immersion testing of tanks at 180°C (356°F)

Multi-element or phased array probes

Cross coupling

In the 1-3 composite structure, the isolation of the rods within the polymer material enables the transversal propagation of vibrations to be reduced. In the context of phased array sensors, this reduction in transversal vibrations limits the propagation of an element's signals towards its neighbours (see figure 6). This independence of the functioning of each channel is fundamental to phased array technology, as the formation of the beam is based on each element of the transducers being driven using precise electronic delays.
The level of cross coupling between two elements is, thanks to this technology, less than –40dB

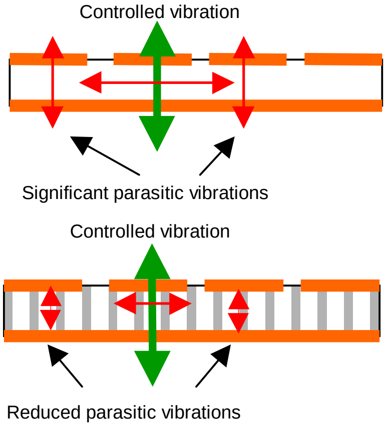

Figure 6 : Diagrammatic view of the reduction of cross coupling in piezocomposite 1-3 materials compared with monolithic ceramics

Examples of applications

Inspection of blade roots and rotor steeples

This inspection, carried out using various miniaturized phased array probes, one of which is shown in figure 7, has enabled many previously untested zones to be inspected.
The use of phased array technology has enabled the use of beam-deflecting wedges to be avoided, and thus inspections to be carried out from restricted spaces inaccessible with other techniques. In addition, the probes' electroacoustic performances have enabled the depth of detection and the accuracy of sizing to be increased (2).

Inspection of steam generator tubes from the inside

The generator tubes of the Superphœnix nuclear power station were inspected from the inside using circular phased array probes, as shown in figure 8.
Here, phased array technology enabled the necessary inspection speed to be obtained. In addition, the active area, made up of 80 elements, was focused by shaping to obtain the desired beam characteristics (3).

Inspection of composite materials and forgings

These two types of inspection require very highly sensitive immersion sensors, with a very high signal / noise ratio and with a perfectly controlled beam profile.

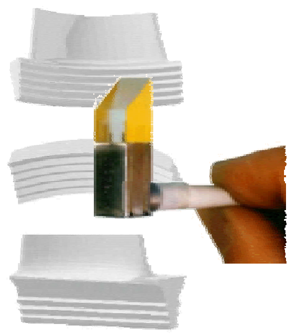

Figure 7 : Miniaturized probe for inspecting blade roots

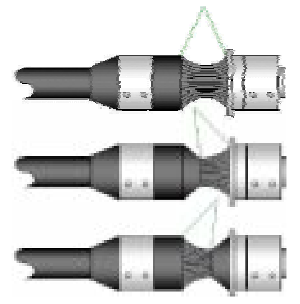

Figure 8 : View of the heads of phased array probes with 80 focused channels used for the inspection of steam generator tubes

By virtue of its performance, piezocomposite technology is naturally adapted to this type of inspection.

Inspection of titanium billets

Titanium billets are inspected using FERMAT sensors (aspherical focusing sensors). These sensors enable very high lateral resolution to be obtained at great depths thanks to their wide active aperture, to focusing by the shaping of their active area, as well as to the electroacoustic performances of the piezocomposites.
This technology can be combined with phased array technology in the form of matrices that allow the beam to be controlled in 3D and thus increasing the precision of the control (4) (see figure 9).

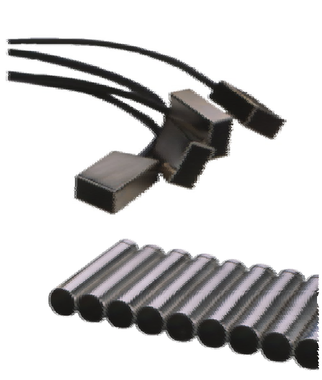

Figure 9 : Batches of immersion probes for various types of inspections

Figure 10 : Set of single-element sensors and FERMAT matrix sensor for the inspection of titanium billets

Conclusion

Imasonic's Piezocomposite 1-3 technology brings about notable improvement in the performances of many inspections on the following points:

- Signal / noise ratio, sensitivity
- Resolution, bandwidth
- Flexibility, speed

In addition, some inspections become possible:

- Inspection of complex parts
- Inspections with strong environmental constraints (temperature, pressure, radiation)
- Inspections in a difficult industrial environment (vibrations, polluting chemical agents)

References

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