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IMPROVEMENTS OF ULTRASONIC INSPECTIONS THROUGH THE USE OF PIEZO-COMPOSITE TRANSDUCERS

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ABSTRACT :

The improvement of the UT inspections performances, and especially the defects characterization, needs first of all the design and the use of transducers with high electrical and acoustical characteristics. The technology of the 1-3 composites materials recently brought in the field of non-destructive testing applications, allows to make decisive progress in the improvement of the above parameters. The exceptionnal piezo-electrical properties of the composite materials, their shaping capacity, their thermal properties and other very good features of these materials already under control, allow the manufacturing of a new generation of transducers, by being released of many restrictions of the conventional technologies : ceramics or piezo-electrical polymers. 3 examples of applications in the nuclear field show all the benefits of this technology and allow to forecast a large diffusion in the near future.

INTRODUCTION

The development of ultrasonic techniques in the field of Non Destructive Testing is determined by the availability of outstanding transducers, adapted to testing conditions, allowing the control and the improvement of the forming of ultrasonic beams. The piezo-electrical materials which constitute the active part of the transducer involve the electroacoustical conversion of electrical pulses into acoustical pulses. Designers and users of transducers can benefit from new possibilities thanks to the development of new piezo-electrical materials made of ceramic-polymer composite. The intimate association of several materials within a composite structure exploiting the combination of their owns properties is at the origin of the interest of all the composite materials.
The IMASONIC company has developped a composite materials technology called "1-3 structure" which permits the manufacturing of innovating transducers used in the fields of Non Destructive Testing, medical diagnosis, or submarine imaging.

1-3 PIEZO-COMPOSITE MATERIALS

The structure of these materials, illustrated on the table n°1, is made of thin ceramic rods (which present a mechanical continuity following one dimension of the space) embedded into a polymer matrix (which present a mechanical continuity following three dimensions of the space). Used as plates and equiped of electrodes on their main sides, these materials offer many advantages compared with piezo-electrical transducers generally used in the field of Non Destructive Testing.

The physical properties of the piezo-composite materials, particularly their dielectric, elastic and piezo-electric properties, depend on the properties of the constituent materials, on the relative proportion of these materials and also on geometrical parameters of the microstructure. In practice, the microstructure of the material is defined so that all the waves subject to excitation could have a wavelenght higher than the microstructure itself. If this condition is respected, the piezo-composite material behaves like an homogeneous material which could be described with simple parameters comparable to classical material parameters : figure n° 1.

The variation laws of the main parameters of the piezo-composite materials can be modelized. The figure 2 presents these variation laws for the following parameters : dielectric permitivity ε, acoustical impedance **Z**, longitudinal wave velocity **Vl**, electromagnetic coupling coefficient **kt**, according to the volume of ceramic material within the composite. It is particularly interesting to consider the variation of **kt** which constitutes the most important parameter in so far as it shows the capacity of the piezo-composite material to turn reciprocally electrical energy into acoustical energy. For a 1-3 piezo-composite, **kt** is higher than the one of the constituent ceramic material in a large range of volume. This surprising property comes from the effect of release of the lateral constraints within the ceramic bars which provides a best ability to transform energy than the ceramic in solid plate.

CHARACTERISTICS OF 1-3 PIEZO-COMPOSITE MATERIALS

The properties of these materials imply a certain number of specific characteristics as :

- acoustical impedance : located between the one of the polymer material and the one of the ceramic material. In practice, it is adjusted between 8 and 12 MRayleigh, which allows a good tranfer of energy in a large frequency band when the impedance of the coupling medium is low, which is always the case for immersion testing.
- coupling coefficient : its high value also contributes to the increase of energy transfer and to the widening of the bandwidth. These materials, thanks to the double effect of a low acoustical impedance and a high coupling coefficient, make possible a quite important improvement of the ratio sensitivity/bandwidth compared to the performances of the traditionnal transducers.
- electrical impedance : the judicious choice of the constituents and their respective proportions allow to adjust the electrical impedance and to favour, in that way, the matching of the transducer to its electrical environment.
- shaping : it is linked to the thermal and mechanical properties of the polymer phase.
- lateral modes : they are strongly attenuated with this type of material and associated parasitic effetcs are consequently reduced.
- cross coupling : this parameter is very important for the design of multielements transducers. The anisotropy of these materials on the mechanical, dielectrical and piezo-electric aspects allows, thanks to a simple deposit of electrodes having the required geometry, to surround the active zones which have a low interaction with the adjacent zones.

We have just listed the main properties of the transducers using piezo-composite technology. Specific properties have also been developped in the field of withstanding in power, temperature or for the realization of very small or very large transducers.

SOME APPLICATIONS OF PIEZO-COMPOSITE PRODUCTS IN THE FIELD OF N.D.T

In the framework of its development of new ultrasound NDT methods, the CEA/STA has the opportunity to design high performance focused transducers, particularly for the dimensioning and the characterization of the defects. We present below 3 examples which show, each in their own field, the decisive advantages provided by this technology concerning the resolution of advanced problems of control.

❶ *15 MHz FOCUSED TRANSDUCERS FOR TUBE INSPECTION*

The scope of this application is to inspect steel tubes from the inside, 1.2 mm thick and with an inner diameter of 19 mm. The defects can be lacks of thickness or deformations (inspection in longitudinal waves at 0°) and the detection and the dimensioning of IGA and IGSCC types of flaws (inspection in shear waves at 45°). In the 2 situations, it is important to work at high frequency, with an important damping in order to improve the temporal resolution, and with a maximum S/N (signal-to-noise) ratio to detect low echoes such as diffraction from defect tips. Another important parameter is the control of the shape of the focused beam. The height of the required space of the housing is restricted to 5 mm, with a maximum outer diameter of 8 mm. Actually, the important convergence of the beam limits the active diameter of the piezo to 5 mm. The use of conventional transducers from various sources didn't allow to satisfy the requirements on different points :

- impossibility to excite correctly at a high frequency the transducers, particularly because of the strong loss of impedance matching with the coaxial line of 50 Ω impedance,
- difficulty to reach a damping better than 50% for a 5 mm high housing,
- insufficient S/N ratio to clearly distinguish diffraction radiations, because of an insufficient absolute sensitivity and a too high acoustic noise level.

The implementation of piezo-composites increased sufficiently the performances to make the control efficient. These improvements regards :

- a better impedance matching (compensation of the reactive part) : the central frequency of the echoes is largely raised and that, in a reproductive way : at the present time, we work until 16 MHz,
- the damping which easily reaches 60 to 70%,
- the S/N ratio which is improved by 6 or 12 dB compared with conventional transducers (no attenuation in the lens, best intrinsic sensitivity of the piezo-composite and reduction of spurious and backward echoes).

The figures 3 and 4 illustrate these improvements through the example of a typical echo obtained on an external slot of 10% of the thickness of the tube detected by its corner echo.

❷ *WIDE APERTURE FOCUSED TRANSDUCERS*

For the control of thick structures, the dimensioning of the defects requires the use of well focused beams.
The two main parameters which regulates the diameter of a beam are the frequency and the diameter of the piezo-composite. These two parameters cannot be modified in a significant manner because of the presence of a stainless steel covering on the control face and the limitations of the required space of the transducer. One of the possibilities we have studied is the improvement of the focusing surface. In fact, conventional transducers use a toroidal acoustic lens sticked on a flat piezo-ceramic having a diameter of 100 mm and a frequency of 1 MHz. This lens only allows an approximate corrective action on the aberrations caused by the curved surface of the interface water/metal associated to a wide aperture. The consequences are an weak sensitivity and a widening of the beam compared to theoretical values.

Thanks to a software for optimum design of aspherical surface developped by the CEA/STA, coupled with the software CHAMP-SONS for the acoustical field, we have acheived a transducer having a piezo-composite directly formed according to the optimum focusing surface. The main advantage is the suppression of the disturbances generated by a thick lens. It has been possible to raise the impedance of the transducer to 50 Ω unreactive, which optimizes its electrical functionning.

The figures 5 and 6 show the improvements obtained in the field of sensitivity and the narrow geometry of the beam on a cross section of the beam drawed for the two types of transducers thanks to the echo on a 2 mm side drilled hole located at the focusing depth.

❸ *ARRAY TRANSDUCERS*

The modelling demonstrates that, if we consider a matrix array composed of pixels regularly divided in the opening, several hundreds of elements would be necessary to obtain significant and simultaneous variations of the parameters "refracted angle" and "depth of focusing", while keeping a sufficient quality of beam characteristics.

However, it has been shown (2) that considering the shape of the equiphase surfaces which allow the optimum focusing, there is a certain number of symmetries allowing regroupings of the pixels in the form of long and curved electrodes. For equal acoustic performances, the number of elements necessary for the array goes to tens, indeed one hundred, according to variation ranges required for the acoustical parameters.

The realization of arrays using this method of electrodes' sectoring became easier with the technology of piezo-electric composites materials which makes feasible any shape of electrodes while improving notably the intrinsic acoustic performances of the array : very low cross coupling, good sensitivity, good damping and good reproductibility. This point is developped in (3). In the figure 7 is presented the example of a 1 MHz ∅ 100 mm array, composed of 60 sectorized annular electrodes. In this case, it has been posssible to verify the good homogeneity of the central frequencies, the dampings and the electric impedances. The level of cross coupling is lower than -40 dB on two adjacent electrodes.

CONCLUSIONS

The interest of the 1-3 piezo-composite structures is now illustrated in various applications of Non Destructive Testing. The improvement of the S/N ratio, of the focusing and the electronical control of the beam are part of the numerous ways in which the designer of Non Destructive Testing systems can, from now on, benefit from this new technology.

References :

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	lead metanobiate	**lead zirco-titanate PZT**	**PVDF, PVDF - TrFE**	**1-3 composite**
acoustical impedance (Mray)	20	30 à 32	4.5	8 à 12
coupling coefficient	0.3	0.45 à 0.5	0.2 à 0.3	0.5 à 0.7
dielectrical constant	300	250 à 2000	6	200 à 600
density (g/cm$^{3)}$	6.2	7.8	2	3.5 à 4

Table 1 : comparative chart of the electroacoustical properties for different piezo-electrical materials