A NEW PIEZOCERAMIC MATERIAL FOR A SANDWICH TYPE TRANSDUCER USED FOR NDT OF CIVIL ENGINEERING STRUCTURES

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1. INTRODUCTION

Nondestructive Testing (NDT) is the science able to identify some physical and mechanical properties or defects in a piece of material or structure, without altering their end use capabilities. For heterogenous materials, such as concrete, the NDT can become a difficult task. Different materials and structures need a proper frequency of the transducer used. The NDT of materials and structures use mostly piezoelectric transducers which may cover a wide range of frequencies. The essential tool for NDT with piezoelectric transducers is the piezoelectric element which transmits an ultrasonic puls. The returning signal from the tested object bears all the information about the structure, properties or damages of the material. In case of high frequency transducers the piezoactive elements are easier to make. But for lower frequencies some difficulties arises concerning the dimensions of the piezoelectric elements which become extremely large and implies high voltage signals.

2. OBJECTIVES

In order to overcome the difficulties encountered by the construction of a piezoelectric transducer of low frequency which can be succesfully apply for NDT of concrete and structures in civil engeneering we designed and constructed a rather simple piezoceramic active element to be used at lower frequency for transducers destined to NDT. Therefore, the objective were:

- **To designe such a constructions for the piezoceramic active element so as to be able to furnish any low frequency at desire;**
- **To use piezoceramic active elements of disk shape;**
- **To make a sandwich type active element from simple piezoceramic disc.**

3. EXPERIMENTAL

One of the most important tools for NDT investigation is the piezoelectric transducer, which can work either as source or detector of ultrasounds, playing both functions due to the reversibility of the piezoelectric effect. Efficiency for emitters and sensivity for receivers are the fundamental characteristics of ultrasound transducers. Both are dependent on electromechanical coupling factor and some other constants of the piezoelectric materials. The simplest piezoelectric transducer consists of a disc shaped piezoceramic element operating in one direction axis of polarization. This piezoceramic element produces the high frequency ultrasonic vibration in response to a short electrical pulse and it receives the reflected high frequencies sound signals and transforms them into electrical signals. For lower frequencies, the dimensions of the piezoceramic element would become so big that it will imply a high power generator. In order to overcome these difficulties a "sandwich" type element can be proposed as piezoactive element, made of a number of thinner discs, glued together and having the polarization directions in opposition. It is then tightly glued on a steel cylinder playing the role of backing material.

Figure 1 shows the X-ray diffractogram of the calcined powder of the material investigated. Only the peaks corresponding to the well known perovskite phase are present and no other foreign phase was detected. The morphology of the calcined and milled powder is shown in the SEM micrograph of fig. 2. The particles are within the nanoscale range with an average grain size of about 200 nm. The structure of the pressed and sintered samples is illustrated in the micrograph shown in fig. 3 on a polished and thermally etched surface. One can see that the samples are well enough densified and the crystallite grain size is just submicrometric though few crystallites with greater sizes, up to around 1 μm can be distinguished.

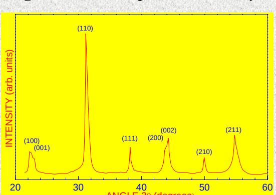

Figure 1 The X-Ray patterns obtained of the calcined powder of the PZT material used in the present investigation

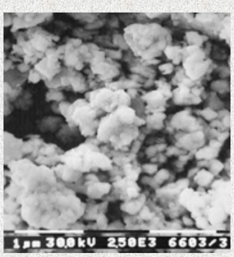

Figure 2 SEM micrograph illustrating the morphostructure of the calcined and milled powder of the PZT material investigated

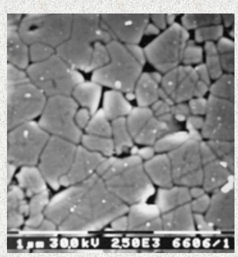

Figure 3 SEM micrograph showing the structure of a sintered sample on a polished and thermally etched surface

The sandwich type piezoactive element, glued on a steel cylinder acting as backing material has two main advantages: 1) the electrical connection are disposed in derivation, thus each disc receiving the whole emf of the driver, much smaller compared to the case of single thick element and consequently a considerable simplification of the electronics can be achieved; 2) the working frequency of such a transducer can be simply chosen by taking the right number of thin piezoactive elements. Figure 4 show the schematic of a sandwich type piezoactive elements and figure 5 illustrates the experimental resonance frequency of such a sandwich element as a function of the number of thin discs. The discs used in this experiment for the sandwich type piezoactive element have a diameter of 25 mm a thickness of 1.8 mm. The resonance frequencies were measured after gluing each pair of two discs to the previously stacked ones which were already glued on a backing steel block with a diameter of 26 mm and a thickness of 15 mm. One can see from figure 5 that the frequency resonance decreases with increasing number of disc pairs.

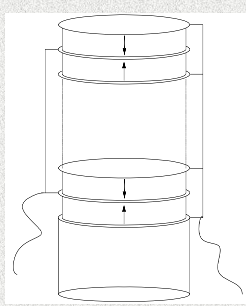

Figure 4 The schematic arrangement of a piezoactive element made from a number of thin disks glued together on a backing steel block

The decreasing can be described by a law approximated by a fifth order polynomial function of the form:

$$f(x) = a + b_1 x + b_2 x^2 + b_3 x^3 + b_4 x^4 + b_5 x^5$$

where the constants a and b's have the following values:

$a = 85.01$; $b_1 = 301.25$; $b_2 = -199.79$; $b_3 = 48.54$; $b_4 = -5.21$; $b_5 = 0.21$

Figure 5 The experimental points (circles) and the calculated curve (full line) of the resonance frequency versus the number of thin disk in a sandwich type piezoactive element

For the practical construction of the transducer we choose the sandwich structure with four pairs of discs (eight thin piezoceramic discs) corresponding to a resonant frequency of 60 kHz. The schematic view of the transducer is illustrated in fig 6.

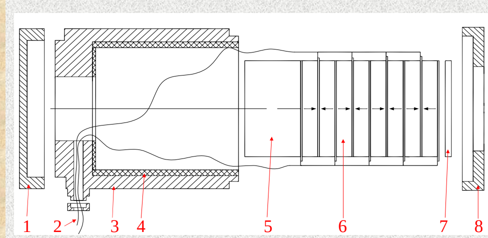

Figure 6 The schemativ view of the sandwich type transducer illustrating the main parts of it: 1-end cap; 2-electrical connections 3-outer case; 4-inner electrical isolation; 5-backing steel block; 6-piezoactive thin disc; 7-protection plate; 8-end cap

4. CHARACTERISTICS OF TRANSDUCER

The resonance frequency is situated around 60 kHz with a minimum impedance of 22 ohms and the antiresonance frequency at 71 kHz with a maximum impedance of 28 kΩ, as san seen in figure 7. Using these values the quality factor Q, calculated by formula $Q=f_w/\Delta f$, gave a value of 5.5 . Here f_w is the working frequency corresponding to the resonance frequency *fr* and Δf is the bandwidth of the oscillation spectrum. Using another approach for *Q*,namely $Q=X/R$ (*X* is the reactance given by $X=2\pi f_\omega L-1/2\pi f\omega C_b$ and *R* the resistance of the electrical branch of the equivalent circuit of the transducer) we obtained *Q=5.44* , in good agreement with the value estimated before.

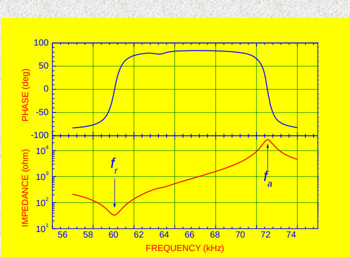

Figure 7 The characteristic electrical spectra of the transducer showing the phase and impedance versus frequency

The acoustical characteristics were determined by using a pair of transducers, one emitter and one receiver, and measuring the ultrasonic output by means of the gain phase analyzer. The transmitted ultrasonic wave within the working range is shown in figure 8. The shape of the acoustical spectrum is that of a product of two lorentzians, each corresponding to a single mode. The data from this figure allow calculating the relative bandwidth at 1.5 dB under the resonance peak and *Q=ω/Δω1.5dB=50.* Using the experimental values for ω and Δω1.5dB we obtained for Q a value of 50 which seems reasonable value for a pair of transducers working in tandem.

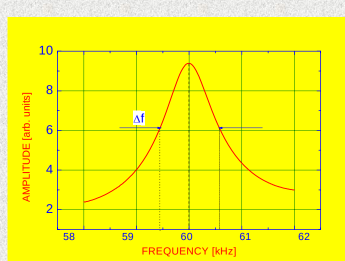

Figure 8 The characteristic acoustical spectrum of a pair of transducer working in the trough-transmission arrangement

5. CONCLUSIONS

A new sandwich type piezoelectric transducer working at 60 kHz was designed and constructed for different materials inspections and NDT investigations.

The transducer is a composite structure made of eight piezoceramic discs of 25 mm diameter and 1.8 mm thickness glued together, with polarization in opposite directions and then glued on a steel cylinder which plays the role of backing material.

The transducer can work either in the *through transmission* or *pulse-echo* arrangement.