PERFORMANCE OF PIEZOELECTRIC CERAMIC TRANSDUCERS WITH MULTIPLE MATCHING LAYERS

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ABSTRACT

A time domain model is used to design sensitive short-response transducers by means of computerized simulations of the impulse response of matched piezoelectric of the impulse response of matched piezoelectric transducers. The effect of matching on the performance of transmitting and receiving PZT-5A transducers working into water load are analyzed. The optimum acoustical characteristics of the quarter-wave length matching layers are determined relatively to a compromise between the sensitivity and the pulse duration. The effects on transducer performance of the existence of bonding layer substantially thinner than a wavelength between the acoustic vibrator and the matching layers has been investigated.

INTRODUCTION

In ultrasonic nondestructive tests and ultrasonic medical diagnosis, it is necessary to transmit and detect short ultrasonic pulses to attain good range of resolution. The usual transducer generates ultrasonic pulses of pulse width much longer than electrical signals. For damping this free oscillation, acoustic backing material is used at the back of the transducer[1] but the backing materials absorb acoustic energy and therefore reduce the transducer sensitivity.

Transducer sensitivity and pulse duration are generally improved by adding single or multiple quarter-wave matching layers between the piezoelectric vibrator and the load medium and this reduces losses between the vibrator and load. In such cases, the acoustic impedance of the matching layers selected are known to act as an important factor in the performance of the transducer. Several theoretical methods for analyzing the optimum mechanical impedance of the intermediate layer which provides broad frequency band have been reported in the literature [2,3,4,5]. such methods suffer from several inherent disadvantages which tend to obscure the exact influence of intermediate layers. For example, the piezoelectric reception process has a strong integrating action which may mask the high frequency components associated with thin bondlines. Furthermore, if a computer model is used, it must be sufficiently accurate to predict the effects of bondline variation.

This paper describes the use of a time domain model of the thickness of piezoelectric transducer for the estimation of matching layers and bondline quality. The model is implemented directly in the time domain, in the form of a recursive digital filter [1]. The optimum acoustical characteristics of the matching layers are determined by defining a compromise between the sensitivity and the pulse duration of the impulse response.

TRANSDUCER EQUIVALENT CIRCUITS

The transducer performs the conversion of electrical energy into mechanical energy, and conversely, the conversion of mechanical energy into electrical energy. There is a fundamental relationship between the properties of the transducer and the techniques have been developed for modelling transducer behaviour and hence predicting the required system response.

There are many computer models describing the behaviour of ultransonic piezoelectric transducers[6-8]. Hargreaves[7] has multilayered piezoelectric transducer connected to any arbitrary electrical load. It uses z-transform techniques[8] to provide a discrete time implementation of the original frequency domain equivalent circuit of Mason (see Berlincourt et al[9]). His computer model is split into two parts. first, the basic transfer function of the loaded piezoelectric element is evaluated in discrete form using the z-transform technique. Secondly, the discrete time responses so obtained are then processed by a nested set of digital filter operations that simulate reverberation in the coupling layers connected to the device active element, and backing and load media connected to these[1].

Three transfer functions are required for the transducer whose equivalent circuit is depicted in Fig. (1). For the transmission response. F_i in Fig. (1) is set to zero, and we require a transfer function relating the voltage at the transducer terminals (v) to the excitation voltage, taking into account the generator impedance in a Thevenin model. Also, for the transmission response, we require the function relating the force generated at the transducer load face (F_o) to the voltage at the terminals (V_{Et}). For the device response when acting as a receiver, V_E in Fig. (1) is set to zero, and we require the voltage at the receiver terminals as a function of the force at the transducer receiving face, F_i.

COMPUTATION RESULTS

Calculation was made using typical data for transducers constructed with lead zirconate titanate (PZT-5A) piezoelectric element [9] with different quarter-wave matching layers. In this computation, the backing medium to be air, and disregarded the thickness of the bonding layers. The transmitter response was obtained for a 20 mm diameter pulse-echo transmitter of 4 MH_z resonance freequency. The electrical impedance of the generator was taken as 5 Ohms. Assuming simple impluse excitation to the transducer, and consider the received echo waveform and its frequency spectrum, at the terminals of the same transducer.

The sensitivity is defined as the maximum height of received pulse, given in terms of volt and the duration pulse is the pulse length, given in terms of time. Let us now examine changes in the performance of transducers with one and two quarter-wave length matching layers and determine the optimum matching layer for the transducer. Table (1) shows the variation of the materials that have been used for the single quarter-wave matching layer with the pulse duration and sensitivity. These variations, for a single matching layer, in sensitivity. These variations, for a single matching layer, in sensitivity and pulse duration as functions of impedance of the materials are shown in Fig. (2). It is clear that the sensitivity is maximized and duration pulse minimized when the matching layer is Glassbeads and Epoxy ($z=4.2\times10^6$ kgm^{-2} s^{-1}) [10]. The variation, for a two matching layer of materials, in

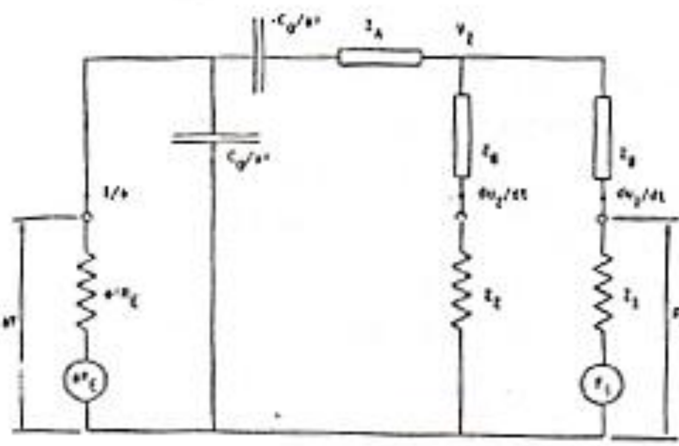

Fig. 1 The equivalent circuit of the transducer

- V_E Thevenin equivalent applied voltage
- R_E Thevenin equivalent impedance
- V Voltage seen across the terminals of the transducer
- C_0 Static capacitance of the piezoelectric element
- Φ Electrical to mechanical conversion factor
- $Z_A Z_B$ Distributed components
- $Z_1 Z_2$ Acoustic impedance
- F_0 Transmitted force
- F_1 Received force

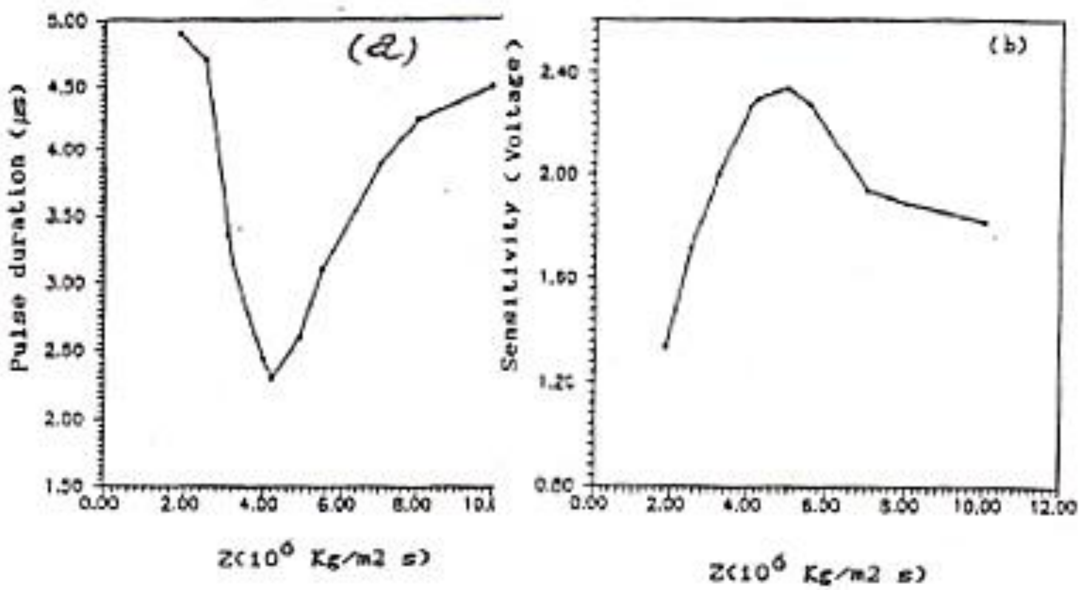

Fig. 2 Dependence of sensitivity and pulse duration on the acoustic impedance of the single matching layer.

sensitivity and pulse duration are shown in Table (II). We varied each of the matching layer materials, and searched for the combination of materials that gives the smallest value of duration can be obtained by use of a glass of arsentic trisulphide (z_1=8x10^6) [4] for the first matching layer and a polystyrene (z_2=2.5x10^6) [11] for the second matching layer. A matching layer arrangement that provides a minimum pulse duration values does not necessarily give a maximum value for sensitivity, because the sensitivity fluctuates much less than the duration pulse. Fig. (3) and (4) show the received waveforms and frequency bandwidth computed for the optimum condition of single and two matching layers. Fig. (3) and (4) shows that as the number of matching layers increases, the received waveform has a relatively shorter tail, the frequency characteristics of the amplitude and phase are considerably improved.

Desilets et al[14] had described a generalized formulation for several front matching layers of an air-backed transducer. From their analysis, the acoustic impedance z of a single λ/4 maching section on the front of the transducer should have a value of $Z_1 = Z_T^{1/3} Z_M^{2/3} = 4.19 \times 10^6$ and to obtain the optimum bandwidth, and for two matching λ/4 layers Z_1 and Z_2 the acounstic impedances are $Z_2 = Z_T^{1/7} Z_M^{6/7} = 2.3 \times 10^5$ and $Z_1 = Z_T^{4/7} Z_M^{3/2} = 8.6 \times 10^6$ where Z_T and Z_M the acoustic impedance of the transducer and the load medium respectively. This configuration is relatively close to one of our optimal configurations.

The actual transducers have bonding layers that couple acoustically the vibrator and matching layers together. The presence of bonding layers in particular may means that transducer sensitivity is not necessarily maximized at a matching layer thickness of a quarter wave-length. Fig. (5) shows the received waveform for the optimum single matching layer with epoxy bond line of thickness 10μm. It can be seen that the sensitivity increased to 3.67 volt and the pulse duration is 4.95 μs. It is clear from all of these results that calculation using the technique proposed in this paper yields an accurate analysis in the design of ultrasonic transducers.

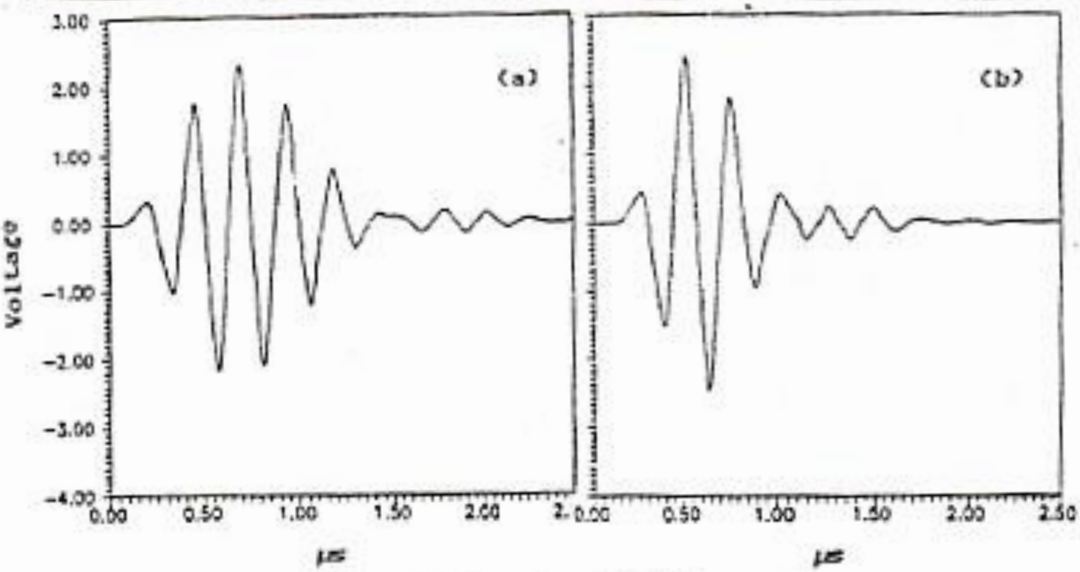

Fig. 3 Received waveforms. (a) Single matching layer.
(b) Two matching layers.

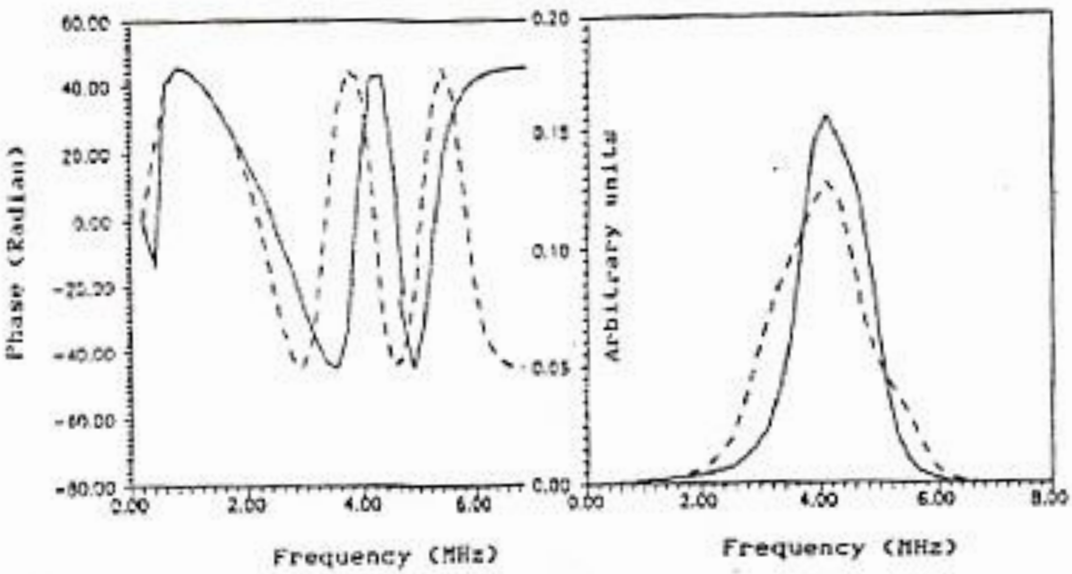

Fig. 4 Frequency response curves. (a) Solid line : single matching layer. (b) Dotted line : two matching layers.

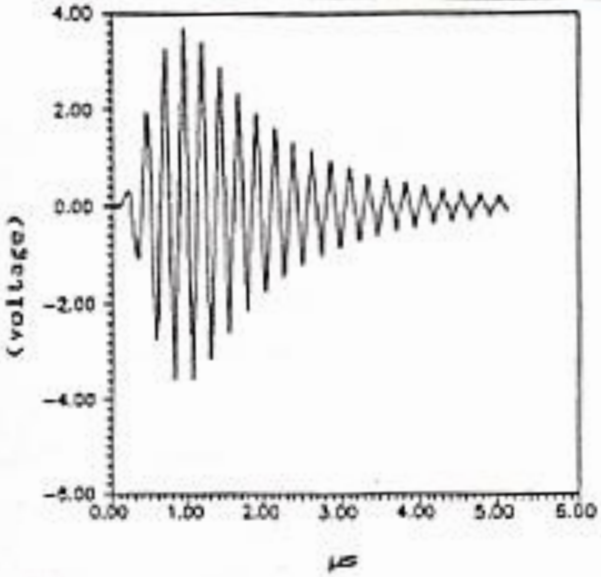

Fig. 5 The received waveform of Figure (3 a) with Epoxy bond lin between the vibrator and the matching layer.

Table (I) variation of single matching layer with pulse duration and sensitivity

Materials for quarter wave matching			Pluse duration (μs)	Sensitivity (Voltage)
type and mixture		impedance (Z) $(Kg/m^2.s)x\ 10^6$		
mathylplaten	[10]	1.85	4.9	1.3
polystyrene	[11]	2.5	4.7	1.7
polymethylmeth-acrylate	[12]	3.2	3.14	2.0
Glassbeads and Epoxy	[10]	4.0	2.44	2.2
Glassbeads and Epoxy	[10]	4.20	2.3	2.3
Melopas	[10]	4.93	2.6	2.3
Al-Epoxy	[13]	5.5	3.1	2.2
Tungsten - araldite	[13]	7.0	3.89	1.9
Glass arsenic trisulpbide	[4]	8.0	4.25	1.8
Tungsten - Epoxy	[13]	10.0	4.5	1.8

CONCLUSTIONS

A discrete time model of the thickness-mode piezoelectric transducer has been used to predict the influence of mechanical layers and intermediate bond lines. The model is obtained from the analysis of the electrical equivalent circuit of a piezoelectric device. The received waveform of ultrasonic transducers with one and two quarter wavelength acoustic matching layers have been analyzed, and found that the response of the transducer appears to improve as the number of matching layers increases. The technique could be extended to incorporate with four matching layers.

REFERENCES

1- M.G.S. Ali and A. Raouf mohamed, Ultrasonic, 30, 5, 311 (1992).

2- M. Redwood, Applied Materials Research, 2,76 (1963).

3- G.K. Lewis, Acoustic imaging, 4, 395 (1979).

4- R.H. Coursant, Ultrasonic Int. conference proceedings 400 (1981).

5- K, Yamaguchi, H. Yagami and T. Fujii, IEEE Trans. Ultrason. Ferroelectrics, Freq. Contr., uffc-33,6,669 (1986).

6- G. Hayward, C.J. Macleod and T.S. Durrani, J. Acoust. Soc. Am., 76, 369 (1984).

7- M. L. Hargreaves, Ph. D. Thesis (1988) Keele University, U.K.

8- R.E. Challis and J. A. Harrison, J. Acoust. Soc. Am., 74, 1673 (1983).

9- D.A. Berlincourt, D.R. Curran and H. Jaffe, Physical Acoustic IA, (Ed, W.P. Mason) Academic, New York (1964).

10- J. Souqet, P. Defranould and J. Desbois IEEE Trans. Son. Ultrason. SU-26, 75 (1979).

11- J. W. Hunt., M. Akditi and F.S. Foster, IEEE Trans. Bio Eng., 30, 454 (1983).

12- G. W. C. Kaye and T. H. Laby, Tables of physical and chemical constants, London, England : Longmous, 1968.

13- G. Kossoff, IEEE Trans. Son. Ultrason., SU-13, 20 (1966).

14- C. S. Desilets, J.D. Fraser, and G.S. Kino, IEEE Trans. Son. Ultrason., SU-25, 115 (1978).

Table (II) variation of two matching layers with pulse duration and sensitivity

Materials for quarter wave matching				Pulse duration (µs)	Sensitivity (Voltage)
first matching layer		Second matching layer			
Type	z_1 Kg/m^2.s) x 10^6	Type	z_2 Kg/m^2.s) x 10^6		
Glass arsenic trisulphide	8.0	Polystyrene	2.5	2.2	2.4
Glassbeads and epoxy	4.2	Rubber	1.4	2.35	2.34
Al- epoxy	5.5	methylplaten	1.85	2.94	2.2
Glassbeads and epoxy	4.2	methylplaten	1.85	2.97	2.0
Al-epoxy	5.5	polystyrene	2.5	3.04	2.0
Glass	11.4	Glassbeads and epoxy	4.2	4.48	2.4