MEASURING THE THICKNESS AND ELASTIC PROPERTIES OF ELECTROACTIVE THIN-FILM POLYMERS USING PLATEWAVE DISPERSION DATA

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INTRODUCTION

- Electroactive thin-film polymers are offering unique capabilities for sensors and actuators.
- Muscle mechanisms and micro-electro mechanical systems (MEMS) are emerging technologies that increasingly needing such thin film polymers.
- The obtain actuation/sensing capability piezoelectric, electrostrictive or electrostatic effects are employed.
- The films are used in the thickness range of tens to hundreds of microns and the strain can be linearly or quadratically proportional to the electric field.
- In addition to the thickness change. the film vibrates as a plate structure.
- Measuring the thickness and its change under activation of an electric field anddistinguishing between the thickness value and the film vibration amplitude is a complex and costly problem.
- Most methods, such as interferometry, eddy-current and capacitance, are measuring the location of the top surface of the film assuming that the rear surface stays stationary.

TECHNOLOGY NEED

- The determination of the thickness of thin films simultaneously with the position of their surfaces (that move as a result of vibration) cannot practically be made with conventional methods.

- Electrostrictive polymers encounter internal polymer restructuring leading to potential change of the elastic properties.

- Knowledge of the elastic constants and their change is critical to the understanding of the electrostriction phenomena and the ability to distinguish it from electrostatic activation.

ULTRASONICS AS A CHARACTERIZATION TOOL

- Ultrasonic pulse-echo offers an ideal tool for simultaneous determination of the location of the top surface, i.e., vibration amplitude, and the film thickness.

- Obtaining an acceptable resolution for 50 to 100-μm thick films requires frequencies in the range of 50-MHz and above, which is beyond the capability of conventional ultrasonic systems.

- Plate wave measurements allow to determine the thickness of thin films using much lower frequencies and to obtain significantly higher resolution.

- Using dispersion curve measurements one can also determine the elastic constants of the film.

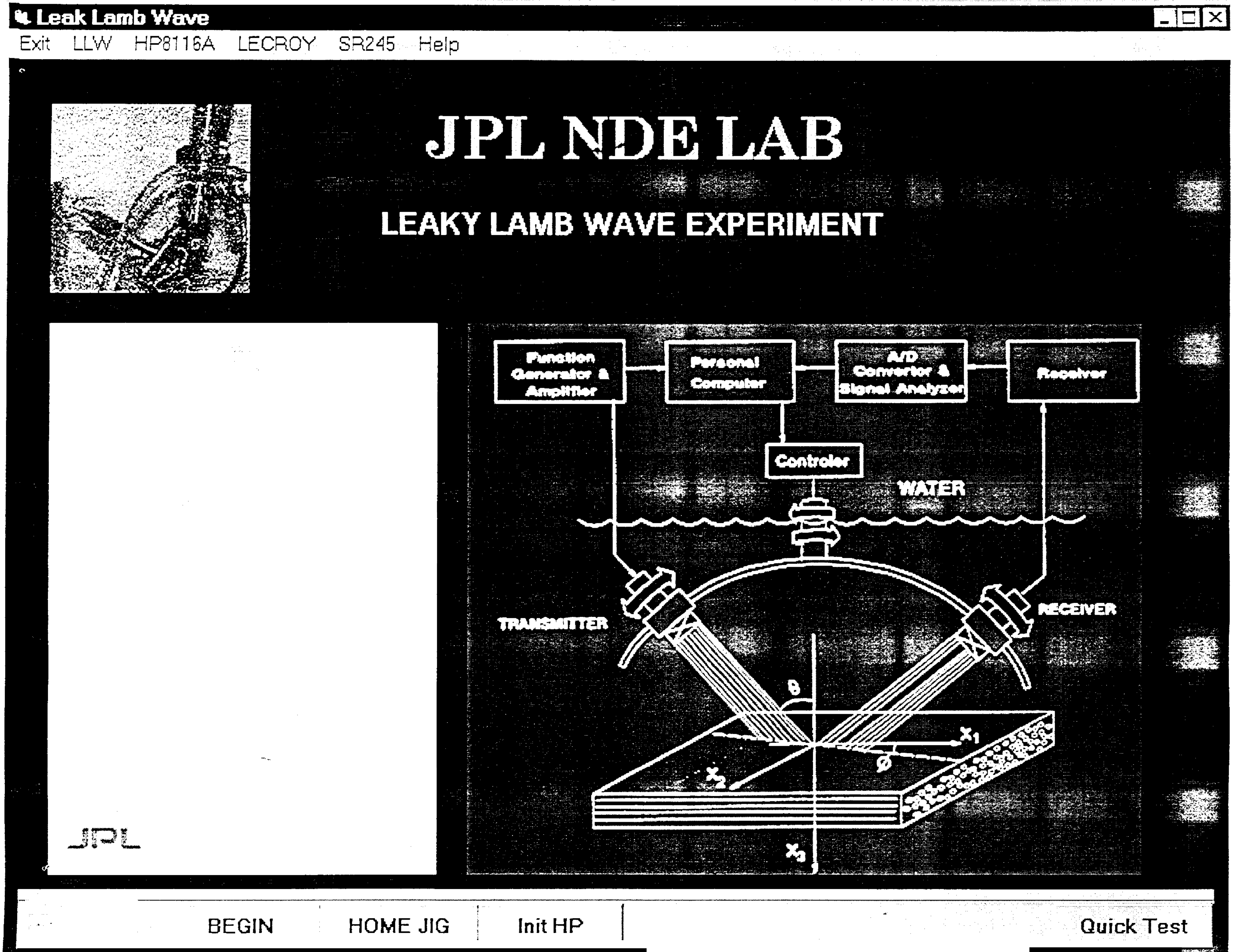
EXPERIMENTAL SETUP

- A pair of transmitter/receiver transducers is used in a pitch-catch arrangement.

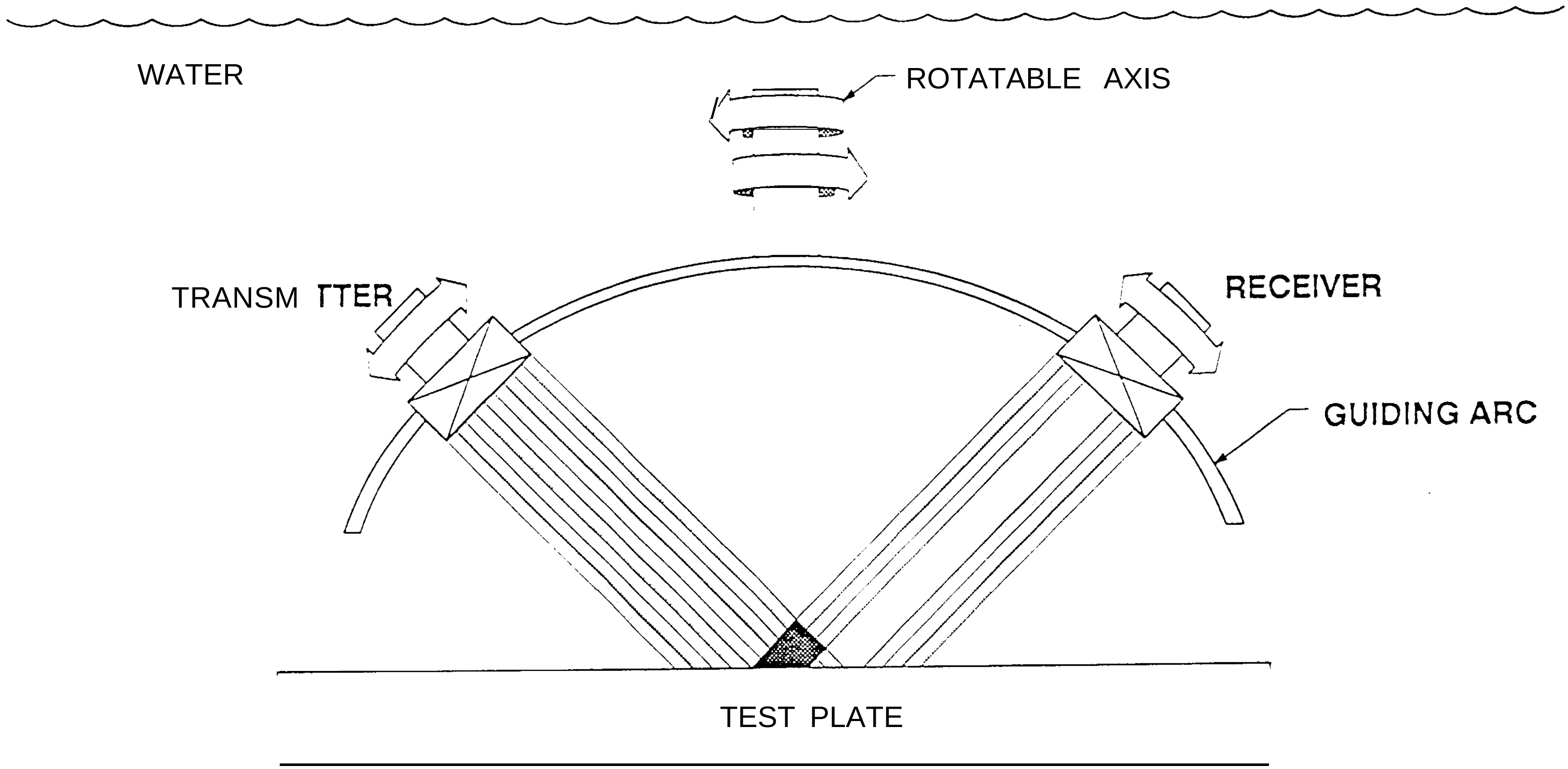
- The specimen film is immersed in coupling medium and the launched wave is monitored by the receiver.

- The amplitude spectra of the reflected wave as a function of frequency is used to determine the dispersion curve of the leaky guided waves generated by the specimen.

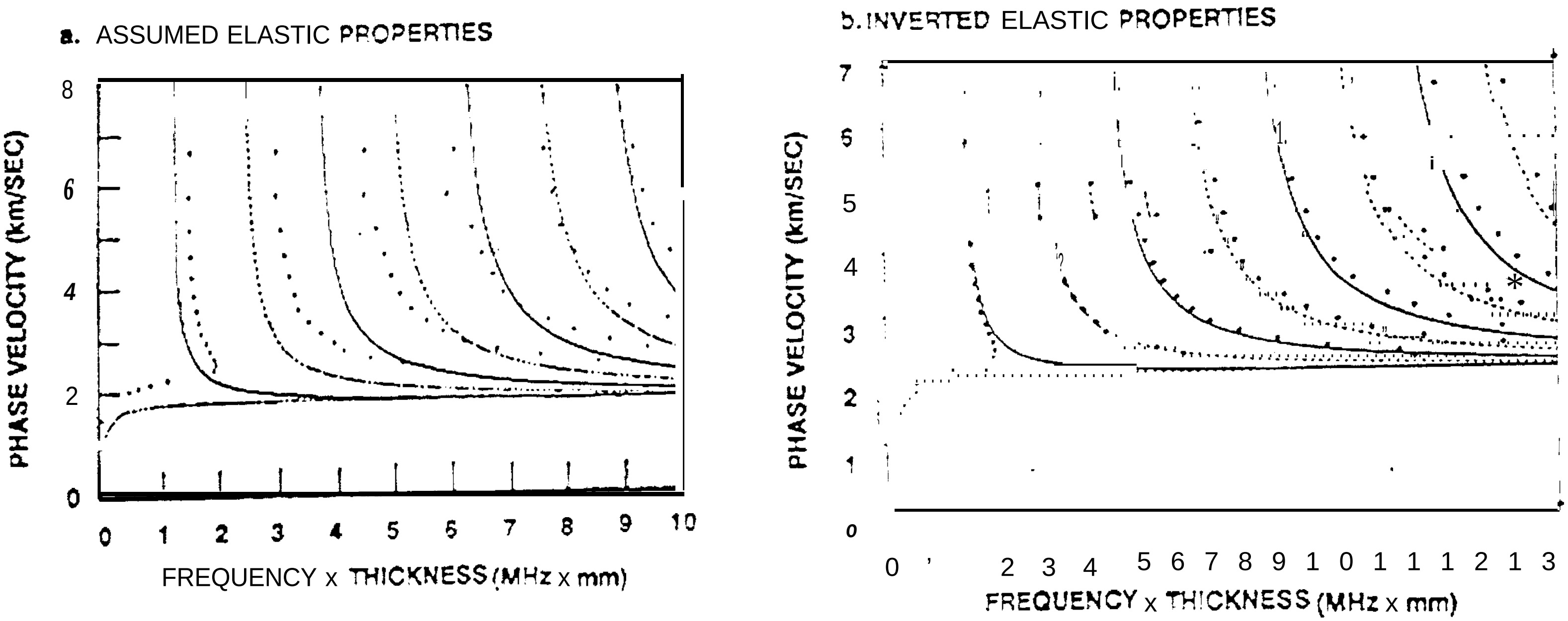
- The dispersion curves are strongly affected by the film thickness and its elastic constants.


Leak Lamb Wave
Exit
LLW
HP8116A
LECROY
SR245
Help
JPL NDE LAB
LEAKY LAMB WAVE EXPERIMENT
Function Generator & Amplifier
Personal Computer
A/D Convertor & Signal Analyzer
Receiver
Controler
WATER
TRANSMITTER
RECEIVER
JPL
BEGIN
HOME JIG
Init HP
Quick Test

EXPERIMENTAL SETUP FOR COMBINED PBS AND LLW



Leaky Lamb Wave (LLW) Dispersion Curve For A Graphite/Epoxy Laminate



Nonlinear Electroelastic Equations

Stress equations of motion:

$$K_{Lj,L} = \delta_{jM}\ \rho^o \ddot{u}_M$$

Charge equations:

$$\hat{D}_{L,L} = 0$$

where ρ^o, u_M, K_{Lj}, $\hat{D}_L$, and δ_{jM} denote the reference mass density, the mechanical displacement, the total Piola-Kirchhoff stress tensor, the reference electric displacement vector, and the translation operator (where capital–reference state, lower case - present state.)

The parameters can be defined as

$$\hat{D}_L = JX_{L,i}D_i,\ y_i = y_i(X_L, t)$$

$$J = det y_{i,L},\ y_i = \delta_{iM}(X_M + u_M)$$

$$K_{Lj} = H_{Lj} + M_{Lj},\ \hat{D}_L = \epsilon_0 \hat{E}_L + \hat{P}_L$$

where ϵ_0 is the electirc permittivity of free space, and

$$H_{Lj} = \rho_0 y_{j,M} \frac{\partial \chi}{\partial E_{LM}}$$

$$P_L = -\rho^0 \frac{\partial \chi}{\partial W_L}$$

$$M_{Lj} = J X_{L,i} T_{IJ}^{ES},\ E_L = J X_L\ E_i$$

$$T_{ij}^{ES} = \epsilon_0 (E_i E_j - \frac{1}{2}(y_{i,L} y_{i,M} - \delta_{LM})),\ W_L = y_{i,L} E_i$$

where T_{ij}^{ES} is the symmetric Maxwell electrostatic stress tensor, E_{LM} is the material strain tensor, and W_L is the rotationally invariant electric variable. The Gibb's free energy function $\chi = \chi(E_{KL}, W_L)$ is defined through

$$\begin{aligned}\rho_0 \chi = \frac{1}{2} c_{ABCD} E_{AB} E_{CD} \quad e_{ABC} W_A E_{BC} \\ -\frac{1}{2}\xi_{AB} W_A W_B - \frac{1}{2} b_{ABCD} W_A W_B E_{CD} \\ -\frac{1}{6}\xi_{ABC} W_A W_B W_C \\ -\frac{1}{6} d_{ABCDE} W_A W_B W_C E_{DE} \\ -\frac{1}{24}\xi_{ABCD} W_A W_B W_C W_D\end{aligned}$$

$$W_L = -\phi_{,L}$$

where c, e, ξ b are elastic, piezoelastic permeability and electrostrictive constants, respectively.

Equations for Small Strain Elements

Constitutive Equation

$$T_p = c_{pq} S_q - e_{kp} E_k - \frac{1}{2} \hat{b}_{klp} E_k E_l$$

$$D_l = e_{lq} S_q + \epsilon_l k E_k + \frac{1}{2} \chi_{kjl} E_k E_j$$

where the contract notation is used, i.e. 11,22,33,23,31,12 = 1,2,3,4,5,6, respectively. or

$$S_q = s_{qp} T_p + d_{kq} E_k + \frac{1}{2} \beta_{jkq} E_j E_k$$

with

$$d_{kp} = e_{kp} s_{pq}, \beta_{klq} = \hat{b}_{klq} s_{pq}$$

$$s_{rp} = c_{rp}^{-1}$$

where S_q is the contracted strain tensor, and d_{kq} and β_{kl} are the piezoelectric constants and nonlinear electrostrictive constants, respectively.

Equations for Thin Elements (plane stress)

$$T_{3m} = 0, D_{3,3} = 0, D_3 = D_3(X_1, X_2, t)$$

$$E_1 = E_2 = 0, E_3 = -V/t.$$

where V is the driving voltage, and t is thickness of the element. Then the constitutive equations reduced to

$$S_q = s_{qv}T_v + d_{3q} + \frac{1}{2}\beta_{33q}E_3^2$$

$$D_l = d_{lv}T_v + e^t_{l3}E_3 + \frac{1}{2}\chi_{33l}E_3^2$$

where v= 1,2, 6., or

$$S_1 = s_{11}T_1 + S_{12}T_2 + d_{31}E_3 + \frac{1}{2}\beta_{31}E_3^2$$

$$S_2 = s_{12}T_1 + S_{11}T_2 + d_{31}E_3 + \frac{1}{2}\beta_{31}E_3^2$$

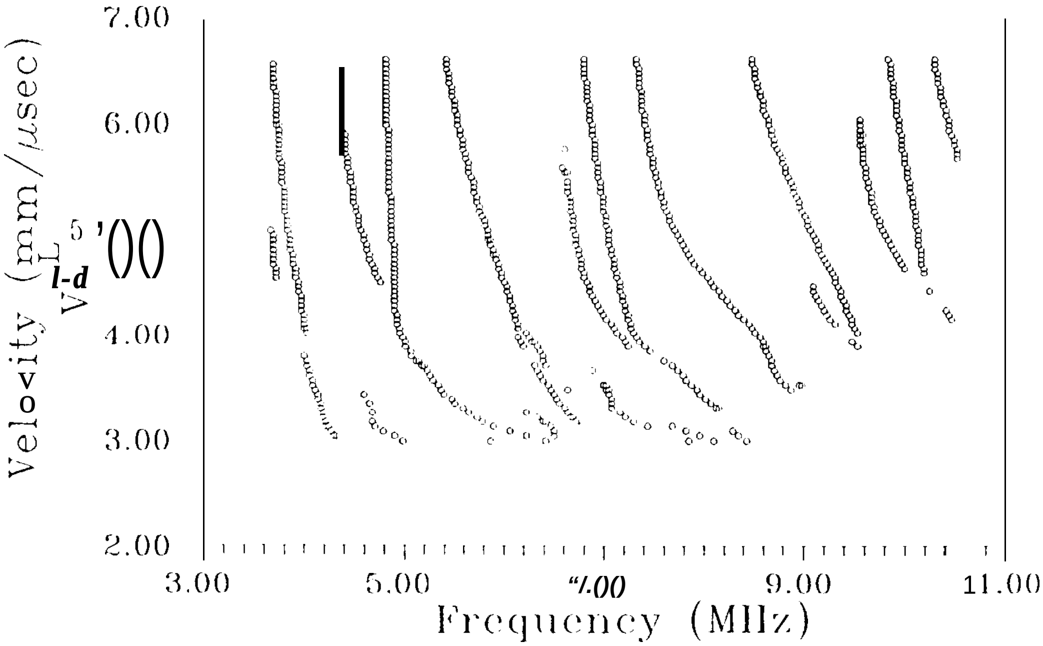
$$S_3 = s_{13}T_1 + S_{13}T_2 + d_{33}E_3 + \frac{1}{2}\beta_{33}E_3^2$$

$$S_6 = s_{66}T_6, S_4 = S_5 = D_1 = D_2 = 0$$

$$D_3 = d_{31}(T_1 + T_2) + \epsilon^T_{33}E_3 + \frac{1}{2}\chi^T_{33}E^2_{33}$$

Stress-Free Thin Element Subject to Large Electric Fields

$$S_1 = S_2 = d_{31}E_3 + \frac{1}{2}\beta_{31}E_3^2$$


Velocity (mm/μsec)
7.00
6.00
4.00
3.00
2.00
3.00
5.00
9.00
11.00
Frequency (MHz)

SUMMARY

- Leaky lamb wave measurements were used to determine the thickness and the elastic properties of electroactive thin film polymers.

- Results show that LLW dispersion data can be used to measure thin-films thickness at high resolution using significantly lower frequencies than possible with pulse-echo.

- These measures also allow simultaneous determination of the elastic constants.