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THE USE OF A LIQUID-DROP-COUPLANT IN SURFACE WAVE TRANSFER TO A NON-PIEZOELECTRIC MEDIUM

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INTRODUCTION

Generation of high frequency (>10 MHz) surface waves on a piezoelectric is simple /1/, but on non-piezoelectric materials the problem arises of how such waves can be excited easily and efficiently. A possible means is the transferring of a wave system generated on a piezoelectric substrate, directly or through a coupling medium, to a non-piezoelectric substrate. A few methods have been considered by various workers /2/. One technique which has received little attention is the use of a liquid-drop-couplant which was first tried in this laboratory briefly /3/, and so in view of the objective of propagation on isotropic (ceramic) materials it was decided to conduct a comprehensive investigation of the possibilities of the liquid-drop-couplant.

In essence the system is shown in fig.1 with a magnified diagram of the liquid drop shown in fig. 2. Rayleigh surface waves generated by the transmitting interdigital transducer (i.d.t) T on the piezoelectric substrate I, propagate along the free surface into the solid/liquid region where the surface waves radiate a beam of compressional waves into the liquid at an angle θ_I. Optimum surface wave transfer to the substrate II is achieved when θ_I and θ_{II} satisfy the relationships

$$\sin\theta_I = \frac{v_c}{v_{R(I)}} \qquad \text{and} \qquad \sin\theta_{II} = \frac{v_c}{v_{R(II)}} \tag{1}$$

where v_c, $v_{R(I)}$ and $v_{R(II)}$ are the compressional wave velocity in the liquid and the Rayleigh wave velocities on the substrates I and II respectively.

THEORY

Before describing the experimental technique a brief reference will be made to the development of a simple theory of the transfer process. By way of introduction the definitions of essential parameters will be stated.

Transfer: the transferrence of the surface wave system from one material surface to another.

Foward transfer: the transferrence is from generating to receiving substrate, reverse transfer being in the opposite direction.

Mode conversion: the change of longitudinal waves in the liquid to surface waves when incident at the critical angle θ_{II} on the solid.

Coupling distance (d_o): the length of liquid/solid interface over which conversion effectively occurs.

Couplant: the intermediate liquid medium between generating and receiving surfaces.

Transfer efficiency: the ratio of wave energy density on the free surface of receiving substrate to that on the free surface of generating substrate.

An exact theoretical analysis of the liquid-drop-coupling is complex, but an approximate treatment is possible by making the following simplifying assumptions;

1). the surface waves on the free solid surfaces suffer negligible attenuation

and no loss of amplitude is experienced on entering the solid/liquid region.
2). Rayleigh waves continue to propagate along the solid/liquid interface and their attenuation is solely due to radiation of compressional waves into the liquid.
3). There is no absorption or beam spreading of the compressional waves in the liquid and the liquid has negligible viscosity.
4). There is conservation of energy in the mode conversion at the liquid/solid interface.

From these assumptions and following a similar analysis to /4/ it is possible to express the transfer efficiency as

$$\eta = A\left\{\frac{\exp(-\alpha_I' z) - \exp(-\alpha_{II} z)}{\alpha_{II} - \alpha_I'}\right\}^2 \qquad (2)$$

where α_I and α_{II} are the attenuation constants of the waves along the solid/liquid interfaces of the substrates I and II respectively and z is the coupling distance as shown in fig.2. A is a constant dependant on the materials.

$$\alpha_I' = \alpha_I(\cos\theta_{II}/\cos\theta_I) \qquad (3)$$

Optimum transfer occurs when

$$z = \left[\log_e(\alpha_I' - \alpha_{II})\right]/(\alpha_I' - \alpha_{II}) \qquad (4)$$

Attention is drawn to an expression recently reported by /5/, who derived a similar expression as (2) above and have the constant term

$$A = 4\alpha_I'\alpha_{II} \qquad (5)$$

APPARATUS

An apparatus was designed for supporting the specimen and positioning the i.d.t substrate which allowed for directional alignment and change in the separation distance of the transmitting and receiving transducers additional to adjustment of the coupling angle γ. The i.d.t. were fabricated by normal photo-lithographic technique on Y-cut Z- propagating lithium niobate substrates for high electro-mechanical efficiency. The transducers static capacitance was tuned with inductance coils and the insertion loss for two transducers used as a delay line on a lithium niobate substrate was measured to be 10 dB. The r.f. driving voltage was supplied by an Arenberg PG 650C pulsed oscillator with a matching-output attenuator the signals being observed on a Hewlett Packard 180C oscilloscope.

EXPERIMENTAL MEASUREMENTS AND RESULTS

Table 1 summarizes most of the results discussed here.

a). Measured values of the two way transfer efficiency η_T were in general higher for coupling with water then with silicon oil. This could be due to the effect of viscosity. Experimental η_T was also generally lower than the theoretical estimates and the theoretical efficiency was approached only in the case of glass and stainless steel with water coupling. This could be partly explained as due to failure to achieve optimum conditions in practice but material

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properties may well be the main cause. This view is supported by the observation that no transfer at all was achieved for copper and brass substrates contrary to expectations of the theory presented. The same observation was made on a variety of materials with low surface wave velocity.

Specimen	γ Water		γ Si oil		η_T dB			z_{max} mm	
	Theory	Expt.	Theory	Expt.	Theory	Expt. water	Expt. Si oil	Theory water	Theory Si oil
Dural	-5.0°	-4.8°	-2.7°	-3.4°	-6.4	-10.4	-11.8	1.2	2.0
Soda glass	-1.4°	-0.7°	-1.0°	-1.2°	-6.2	- 6.8	-11.6	1.2	2.0
Stainless steel	-5.0°	-6.3°	-2.7°	-3.4°	-5.4	- 6.5	-11.5	2.1	3.3
Alumina	10.6°	11.3°	6.1°	7.5°	-6.1	- 9.2	-14.6	2.5	4.2
Copper	-16.8°		- 8.5°		-5.7			1.6	2.6
Brass	- 22.4°		-11.4°		-6.5			1.4	2.3

TABLE 1.

b). i). Equation (1) predicts that there is only one value of coupling angle

$$\gamma = \theta_I - \theta_{II} \qquad (6)$$

for peak transfer. Variations of η with γ however showed more than one peak. Fig. 4 is the variation for dural with water coupling. Only one of the peak angles corresponded to the calculated value although all observations indicated that the waves generated on the specimen at each peak were surface waves.

ii). Variations of η with z agreed with theory. Fig. 6 shows the variation for dural with water coupling. Both fig. 5 and 6 demonstrate that the settings of γ and z are important but small deviations from the calculated values are tolerable.

c). For long term use the best couplants are those liquids with a low evaporation rate. The liquid should also wet both surfaces and form a well defined meniscus. The liquid crystal MBBA was tried. The possibility of aligning its long molecules to improve coupling proved unsuccessful and it tends to change with temperature and in time absorbs moisture from the atmosphere. Ferrox - a stable magnetic fluid with very low vapour pressure was also tested. Experiments were performed to see if the wave transfer could be modified by the application of a magnetic field but no change in the coupling efficiency was observed. However under certain circumstances of applying the magnetic field the position and shape of the drop could be stabilised and could enable the system to be operated in a non-horizontal position.

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Figure 1.

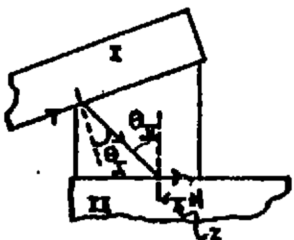

Figure 2.

Figure 1. and 2. Diagrams showing transducer and specimen substrates in the surface wave transfer system.

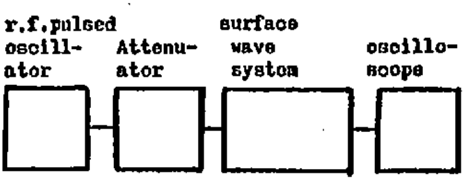

Figure 3.
Block diagram of the measuring system.

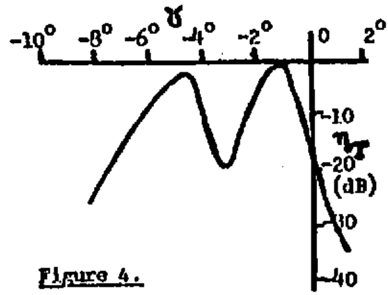

Figure 4.
Variation of coupling efficiency with coupling angle.

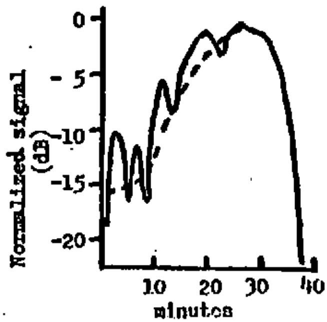

Figure 6. Time variation of signal for polyox couplant.

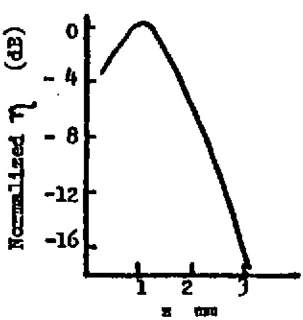

Figure 5

Variation of η with coupling distance.

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A study was also made of coupling with different concentrations of polyox/water solutions and it was observed that there was increased generation of bulk waves as well as surface waves with increasing viscosity. Coupling efficiency of polyox also displayed a characteristic time dependency shown in fig.7. The explanation for this behavior is not yet fully understood. The general trend of the variation (dotted line) has been shown to be due to change in the size of the couplant drop due to evaporation.

CONCLUSION

It has been shown by both theory and experiment that the liquid-drop-couplant is an efficient and simple technique for surface wave generation on isotropic substrates. The unexpected variations of η with γ requires further investigation. The time dependence of the transferred signal in the experiments with polyox may present a method of studying time-dependent phenomena in small samples of pseudo-liquids. The use of magnetic fluids maintained in position by magnetic fields could increase the scope of applications.

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