This is a study of elastic waves diffracted by corrugated metallic surfaces. The corrugations consist of triangular grooves with variable parameters. The results of the narrow band experiments show significant diffraction patterns depending on angle and frequency. In addition, a continuous schlieren system is used to visualize the diffracted orders. Measurements were also carried out using a broadband pulse echo system. The behavior of the received spectra is characteristic of the surface profile. Both front and back surfaces have been investigated.

INTRODUCTION

There is a considerable amount of interest in NDE to study elastic wave interaction with material discontinuities. There are numerous theoretical [1,2,3] and experimental works concentrated on the scattering of elastic waves from single scatterers such as cavities, cracks, etc., in the bulk [4,5] or on the surface [6,7] of materials. The study of elastic wave scattering from multiple structures is not so extensive, however. The scattering of waves from multiple structures, whether they are random or periodic, frequently occurs in materials as the result of grain structure, lamination, fiber reinforcing, multiple defects, surface preparation, etc. The elastic wave diffraction from periodic surfaces has been treated recently by Fokkema and van den Berg [8] but only numerical results are available and only for a few special cases. More extensive results are given for the scattering of electromagnetic waves from periodic and random surfaces by Bechmann and Spizzichino [9].

On the experimental side, ultrasonic wave scattering from periodic surfaces in water has been studied by Jungman et al [10] using ultrasonic spectroscopy. Using an optical model of a diffraction grating, the angular position of the various diffraction orders are related to the grating constant for a given frequency.

In this paper we are addressing the problem of elastic wave scattering from periodically corrugated structures from interfaces and from the bulk of the solid. The following periodic interfaces are considered: (a) solid-air; (b) solid-water; (c) water-solid; and (d) solid-solid. In addition, there are two corrugated structures considered in the bulk of the material: (a) the region of corrugation is much larger than the size of the beam; (b) the region of the corrugation is smaller than the beam size, e.g., a defect with a periodic surface.

DIFFRACTION BY PERIODIC ROUGH SURFACES

Theoretical Considerations. Elastic wave diffraction by a periodic rough surface has been discussed recently by Fokkema and P. M. van den Berg. By using equations of elastodynamics for linear isotropic solids they obtain numerical solutions for the representation integral for the case of sinusoidal periodicity. Incident longitudinal and transverse waves are considered. For a triangular shaped grating surface (which is used in this investigation) the same result is not available although the numerical analysis may be carried out in the same manner. Electromagnetic wave scattering from a triangular shaped grating has been solved using Kirchoff approximations [9]. The intensity of the mth diffracted order is expressed as:

\[ I_m = F_2(\theta_i, \theta_d) \frac{S \sin(m \pi L) + S}{(m \pi L)^2 - S^2} \]

where

\[ F_2(\theta_i, \theta_d) \sec \theta_i \frac{1 + \cos(\theta_i + \theta_d)}{\cos(\theta_i + \theta_d)} ; \]

\[ S = kh(\cos \theta_i + \cos \theta_d) ; \]

\[ \theta_i \] is the angle of incidence measured from normal
\[ \theta_d \] is the angle of the diffraction of the mth order;
\[ h \] is the depth of the groove; and \( k \) is the wave number. The position of the different orders are obtained by the so-called grating equation derived by using phase-delay for the incident and diffracted ray, as

\[ (\sin \theta_i + \sin \theta_d) = m \frac{\lambda}{\Lambda} \]

where \( \lambda \) is the wave length and \( \Lambda \) is the periodicity, \( m = 0, \pm 1, \pm 2 \ldots \). \( m = 0 \) corresponds to specular reflection. For an incident L wave there may be diffracted L waves, diffracted S waves, and diffracted Rayleigh waves. This mode conversion is not treated by the electromagnetic analysis, and the experimental results (which will follow) can only be qualitatively analyzed.
Experimental Methods. In the study of elastic wave scattering from corrugated structures, three experimental arrangements are used: (1) optical schlieren system for water-solid interfaces; (2) a narrowband pulse-echo and pitch-catch experiment for water-solid and solid-water interfaces; and (3) an ultrasonic spectroscopic system to analyze scattering from all the interfaces. This latter technique is the most relevant to this study.

Optical schlieren system. To visualize the beam pattern of the wave scattered from the corrugated surface a continuous wave schlieren system has been used. The system consists of a light source which is a helium-neon laser and a lens system with two large (30 cm diameter) lenses to obtain a large region to visualize the propagation of the ultrasonic beam. The direct light is blocked out by a small circular dot. For the ultrasonic source a high power CW oscillator excites a quartz transducer operated at resonant frequencies of 2, 4, 6, 10, and 12 MHz. The sample with the corrugated surface is placed in a water tank. Both incident and scattered ultrasonic waves are visualized simultaneously by the visual image which is displayed on a TV camera.

Single frequency experimental system. The experiments with narrowband pulses were carried out using a standard ultrasonic pulse arrangement. A quartz transducer and receiver are mounted on a goniometer (schematic diagram is shown on Fig. 1).

ULTRASONIC SPECTROSCOPY. In addition to narrowband experiments, wideband experiments were carried out to study spectral components of the scattered field from corrugated surfaces. A wideband ceramic transducer (bandwidths up to 14 MHz may be obtained) emits a short RF pulse. The scattered signal (from the surface) is received either by the same transducer (pulse-echo) or by another wideband transducer (pitch-catch). The received signal is amplified and gated out in order to select the portion of the signal to be processed. The time domain signal can then be either sent to a conventional spectrum analyzer to obtain the frequency domain information (amplitude or power spectrum) or be sampled and converted to digital information and processed by calculation to obtain the spectrum via a fast Fourier transform. Figure 2 shows a block diagram of the spectroscopy system used.

![Fig. 2 Experimental system for ultrasonic spectroscopy.](image)

A typical spectrum of a normally reflected signal from a perfectly smooth surface is shown in Fig. 3. This spectrum is used as a reference to that of the scattered spectrum from the periodically rough surface. The spectrum of the scattered wave is deconvolved by the reference spectrum. The samples are placed in a water tank and a goniometer system is used to orient the wideband transducer to the required position to control the direction of the incident and the scattered waves. A typical experimental arrangement is shown in Fig. 4. The transmitter is positioned (with an angle $\theta_i = 0$) relative to the corrugated surface which scatters the waves (reflects, diffracts, etc.) to the receiving transducer positioned at angle $\theta_d$.

SAMPLES

Description of the Corrugated Surfaces. There are several parameters describing a periodic surface such as materials on both sides of the interface, boundary conditions, periodicity, depth and shape of the grating, the area of the grating surface,
A number of different types of samples have been chosen in this experiment to study the effects of these parameters on the scattered field. For all samples a triangular shaped grating was used. The periodicity of the grating varied from 100μm to 1732μm. The depth of grooves varied from 50μm to 500μm (kept constant for each grating surface). The materials used were: stainless steel, brass, duraluminum, polystyrene. Each of the grating surfaces are used under different conditions:

1. The corrugated surface faced the incident beam. This corresponds to water-solid interface.
2. The corrugated surface was on the opposite side as the incident beam which propagated through the solid. This is a solid-water interface.
3. The corrugated surface had an air backing and the beam travelled through the solid. This corresponds to solid-air interface.
4. The grating is pressed against a smooth surface in contact with the same solid material. This corresponds to the case of solid-solid interface.

Fig. 3 Power spectrum of the transducer output.

Fig. 4 Schematic of the scattering measurement from a water (eau in French)-metal corrugated interface.

**Diffusion Bonded Titanium Samples.** In addition there are two special types of corrugated surfaces used. These surfaces are inside the bulk of a titanium alloy. By a diffusion bonding process a corrugated titanium surface is bonded together with a smooth titanium surface. After the bonding the only surface is the corrugated surface. On Fig. 5 machined grooves [total surface 2.126 in (5.4 cm)] are shown on the polished titanium surface of 10.2 cm diameter, before the bonding process. The periodicity of the grating is 1.73 mm and the depth is .5 mm. A titanium disk of the same size with a polished smooth surface is diffusion bonded to produce the sample. Another type of sample is prepared the same way but the corrugated surface was confined in a penny-shaped region of 5 mm, prepared on the end of a titaniumplug and driven in through a hole to the large titanium disk. Figure 6 illustrates the surface side view. The corrugation has a periodicity of 300μm. To the corrugated surface which is shown on Fig. 6 is bonded a smooth polished surface titanium disk. In the bulk of the titanium, a so-called penny-shaped crack with a corrugated surface is obtained.

Fig. 5 Corrugated titanium surface before diffusion bonding.

Fig. 6 Photograph of the penny-shaped crack (with periodic surface) in titanium before diffusion bonding.
RESULTS

Schlieren Visualization. Using single frequency quartz transducers for the incident wave, both incident and diffracted waves from the grating are visualized by the schlieren system. On Fig. 7 the transducer and a normally incident 12 MHz wave are shown as diffracted from a water-brass interface. On the surface of the brass is a periodic grating with periodicity of \( \Lambda = 200 \mu m \). The first two diffraction orders are shown on both sides of the incident beam (the zeroth order coincides with the incident beam for normal incidence). The angular position of the \( m = -2, -1, 1, 2 \) can be measured from the photographs as 30°, 30°, 76°, and 82°. The correspondent calculated values using Eq. 2 are 30°, 30°, 76°, 82°. There is some error in the result of the position for the second order, but the positions of the first orders are exactly the same for the experimental results as predicted by the grating equation. On Fig. 8 the diffraction pattern is for a 60° incident 4 MHz wave. The grating is on brass with periodicity of 200\( \mu m \). On the left the zeroth order is shown \( (m = 0) \) which is the specular reflection. The measured position of the diffracted order to the right is 82° and the calculated position for \( m = -1 \) is also 82°.

Results of Ultrasonic Spectroscopy. In the narrowband experiments the relationship between the grating periodicity, the applied frequency, and the angles of incidence and diffraction may be found from Eq. 2. The grating equation (Eq. 2) may also be applied to a broadband signal provided the amplitudes of each frequency component are low enough so superposition is valid. Accordingly, at different angles of incidence the various frequencies will diffract to different angular positions as predicted by the grating equation. On the other hand, by placing the receiver in a

Single Frequency Results. For a normally incident 5 MHz wave the diffraction pattern is shown on Fig. 9 which is measured by a receiver. The brass sample with the periodic surface was facing the incident beam (water-brass interface). The periodicity of the grating is 200\( \mu m \). The zeroth order and the first diffracted orders are positioned according to the grating equation (Eq. 2). The calculated diffracted angle 49° agrees well with the measured value of 46°. The asymmetry in the diffraction pattern may be due to some discrepancies in the grating. Both forward and backward scattering from the same grating are shown on Fig. 10. The grating surface is opposite to the incident beam. The frequency is 14 MHz and the calculated angle for the first order is 32.7°. The measured angle is 34° for these orders.

Fig. 7 Schlieren photograph of incident and diffracted ultrasonic waves from a periodic water-brass interface. \( f = 12 \text{ MHz}; \theta_i = 0°; \Lambda = 200\mu m \).

Fig. 8 Schlieren photograph of incident and diffracted ultrasonic waves from a periodic water-brass interface. \( f = 4 \text{ MHz}; \theta_i = 69°; \Lambda = 200\mu m \).

Fig. 9 Polar plot of an ultrasonic wave diffracted from a periodic brass-water interface.

Fig. 10 Polar plot of an ultrasonic wave diffracted from a periodic brass-water interface.
fixed position a certain frequency which satisfies Eq. 2 will diffract to that position. A special arrangement was investigated when the incident wave is normal to the grating and the transducer is used both as a transmitter and the receiver. In this case the zeroth diffraction order (specular reflection) is also perpendicular to the grating.

Water-Solid Interface. Observed Anomalies. On Fig. 11 the intensity spectrum of a normally incident reflected signal is shown from a grating with 200 µ periodicity on brass. The brass is in water and the water column is about 15 cm to assure far field conditions. The most significant features of these spectra are the two distinct minima occurring at 7.8 MHz and at 10.8 MHz. The energy which is not reflected back at these frequencies to the receiver diffracted to some other position. (This phenomena is similar to the so-called Woods anomalies. Woods has observed missing components from the reflection spectrum of light from a diffraction grating. This anomaly was treated by Lord Rayleigh [11] where he developed a dynamic theory of grating and found conditions that the missing frequency corresponds to a diffraction order directed along the grating. (This phenomena is similar to the so-called Woods anomalies. Woods has observed missing components from the reflection spectrum of light from a diffraction grating. This anomaly was treated by Lord Rayleigh [11] where he developed a dynamic theory of grating and found conditions that the missing frequency corresponds to a diffraction order directed along the grating.)

By rewriting Eq. 2 for normal incidence we obtain the frequency

\[ f = \frac{v}{\Lambda \sin \theta_d} \]  

(3)

taking \( m = 1 \) and \( \theta_d = 90° \), the calculated values for velocity \( v \) from the frequency 7.8 MHz is 1.56 x 10^5 cm/sec and from the frequency 10.8 MHz is 2.16 x 10^5 cm/sec. These values correspond to the velocity of sound in water (1.5 x 10^5 cm/sec) and to the Rayleigh velocity of brass (2.08 x 10^5 cm/sec). It appears that two waves are coupled along the surface, producing the first diffraction order along the grating at these frequencies: (1) a longitudinal wave in water and (2) a mode converted Rayleigh wave. Using such diffraction gratings as a device to convert longitudinal waves to surface waves has been suggested by Ash [12], and it is a convenient way to observe the spectrum such as shown on Fig. 11. The phenomenon apparently depends on the depth of the grating. On Fig. 12 the pulse-echo spectra are shown from a water-brass interface. For each of the four cases the periodicity is \( \Lambda = 250 \mu \) but the depth \( h \) has values of 55\( \mu \), 66\( \mu \), 90\( \mu \), and 125\( \mu \). The frequency minima which corresponds to first diffraction along the surface with the velocity of sound in water should be 6 MHz and with the Rayleigh velocity should be 8.3 MHz using Eq. 3. For

\[ h = 55\mu \]  

there is a sharp minimum at 6 MHz and there is no mode conversion to Rayleigh waves. For \( h = 66\mu \) there are three sharp minima at 6 MHz, at 8.5 MHz, and at 12.8 MHz. The last minimum corresponds to \( m = 2 \), the second diffraction order. At \( h = 90\mu \) again only the 6 MHz minimum is observed and at \( h = 125\mu \) only the 8 MHz. It appears that there is always some anomaly present. The amplitude of the zeroth order (\( m = 0 \)) for the components whose first order (\( m = 1 \)) is always the periodic surface varies with \( h \) (may be periodically). Such variation of the amplitude may be seen qualitatively from Eq. 1. By using \( \theta_d = 0 \) the intensity of the mth diffraction order goes to

\[ I = \frac{2}{\Lambda} \frac{\sin 4\theta_d}{\Lambda} \]  

(4)

This relationship, however, is not applicable to the elastic wave case for evaluating the effect quantitatively. Figure 13 shows these periodic behaviors of Eq. 4. There is a sharp minima at \( h = 66\mu \) and \( h = 125\mu \).

The phenomena of frequency minima in the pulse-echo spectrum is observed also at other water-solid interfaces. Figure 14 shows the pulse-echo spectrum from water-stainless steel interface for grating of \( \Lambda = 1500\mu \) and \( h = 500\mu \). The anomalies again show up at three different frequencies: at 0.1 MHz, 2.2 MHz, and 3.3 MHz, corresponding to three diffracted orders along the surface with water velocity and the 2.2 MHz component corresponds to the Rayleigh velocity \( m = 1 \) for Rayleigh wave and \( m = 2 \) for water (these two effects are separated once the grating has an air backing). The 3.3 MHz is the \( m = 3 \) order.

An interesting case is the water-polystyrene interface. Since the velocity of the shear wave in polystyrene is 1.15 x 10^5 cm/sec, which is less
Solid-Water Interface. The anomalies in the frequency spectrum have also been observed for the case when the grated surface was on the opposite side as the transducer. In this case the beam is diffracted at a solid-water interface from the periodic surface. The main feature of the backscattered spectrum at normal incidence is not the same as for the case of water-solid: frequency minimum (anomalies) observed corresponding to the diffracted orders along the surface with the Rayleigh wave of the solid only but no component with velocity of sound in water is observed (see Table 1).

Fig. 13 Calculated variation of the intensity in the zeroth diffracted order from a water-brass interface as a function of grating depth h.

Fig. 14 Pulse-echo normal incidence spectrum from periodic water-stainless steel interface.

To observe the anomalies in the backscattered spectrum at normal incidence may be a convenient way to measure the velocities of various types along the surface. Table 1 summarizes the frequency minima observed in the backscattered spectrum—for different interfaces—together with the velocities of the identified waves and compared to predicted values.

Solid-Air Interface. By placing an air backing on the grating (sealing off the grated surface from water) the origin of the frequency minima in the backscattered spectrum is easier to identify. On Fig. 16 the backscattered spectra from the stainless steel-air surface with periodicity of 1500 μm is shown. Comparing this to Fig. 14 where the grating is in contact with water, it is apparent that the frequency minimum at 1 MHz on Fig. 14 corresponds to a first diffraction order in water. The 2 MHz frequency minima on Fig. 14 is produced both by $m = 2$ with sound wave in water and $m = 1$ with Rayleigh wave at the stainless steel surface.

On Fig. 16 in addition to that Rayleigh wave component at 2 MHz there is another minima at 2.8 MHz whose origin is not clear at this point.

Fig. 15 Pulse-echo normal incidence spectrum from a water-polystyrene interface.

Fig. 16 Pulse-echo normal incidence spectrum from a periodic steel-air interface.
TABLE 1
ANOMALIES IN THE ULTRASONIC SPECTRUM SCATTERED FROM CORRUGATED INTERFACES

<table>
<thead>
<tr>
<th>Material</th>
<th>Interface</th>
<th>Sample</th>
<th>Spatial Periodicity L (µm)</th>
<th>Post-to-Valley Height H0 (µm)</th>
<th>Frequency Minima (MHz)</th>
<th>Computed Rayleigh Velocity U (ms⁻¹)</th>
<th>U.S. Estimate Rayleigh Velocity VRS (ms⁻¹)</th>
<th>U.S. Estimate Velocity in Water VRS (ms⁻¹)</th>
<th>Other U.S. Measured Velocity (ms⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRASS</td>
<td>WATER</td>
<td>B1</td>
<td>250</td>
<td>55</td>
<td>5.06 (1)</td>
<td>1669</td>
<td>1469</td>
<td>1469</td>
<td>1469</td>
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<tr>
<td></td>
<td></td>
<td>B2</td>
<td>250</td>
<td>66</td>
<td>6.71 (1)</td>
<td>2178</td>
<td>1577</td>
<td>1469</td>
<td>1577</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B3</td>
<td>250</td>
<td>90</td>
<td>6.88 (1)</td>
<td>2178</td>
<td>1577</td>
<td>1469</td>
<td>1577</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B4</td>
<td>250</td>
<td>125</td>
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<td>2023</td>
<td>1533</td>
<td>1533</td>
<td>1533</td>
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<td></td>
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<td>2999</td>
<td>1418</td>
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<td>1418</td>
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<tr>
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<td>D7</td>
<td>1722</td>
<td>500</td>
<td>1.73 (1)</td>
<td>2023</td>
<td>1533</td>
<td>1533</td>
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<tr>
<td></td>
<td></td>
<td>D8</td>
<td>1722</td>
<td>500</td>
<td>1.78 (1)</td>
<td>2023</td>
<td>1533</td>
<td>1533</td>
<td>1533</td>
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<tr>
<td>CARBON</td>
<td>STEEL</td>
<td>S7</td>
<td>1500</td>
<td>500</td>
<td>2.20 (1)</td>
<td>3147</td>
<td>5160</td>
<td>5160</td>
<td>3147</td>
</tr>
<tr>
<td>STEEL</td>
<td>WATER</td>
<td>S8</td>
<td>1500</td>
<td>500</td>
<td>2.02 (1)</td>
<td>3147</td>
<td>5160</td>
<td>5160</td>
<td>3147</td>
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<tr>
<td>POLY-</td>
<td>STYRENE</td>
<td>P9</td>
<td>1000</td>
<td>288</td>
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<tr>
<td>TITANIUM</td>
<td>WATER</td>
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<td>1722</td>
<td>600</td>
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<td>1120</td>
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<td></td>
<td></td>
<td>T11</td>
<td>300</td>
<td>286</td>
<td>0.32 (1)</td>
<td>3502</td>
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</tbody>
</table>

[1] First order of diffraction along the surface.
[2] Second order of diffraction along the surface.

Fig. 17 Pulse-echo normal incidence spectrum from a periodic dural-air interface. However, remained approximately the same. The frequency minima on Fig. 18 is at the same position as on Fig. 17.
Diffusion Bonded Titanium. One problem of NDE is to evaluate the quality of bonding between two solid interfaces. The number of contact points between the two surfaces, their distribution, rms roughness, etc. may be important parameters to consider for quantitative evaluation of diffusion bonding. With that in mind, ultrasonic spectroscopy was applied to the diffusion bonded titanium sample with periodic contact. The details of dimensions are given on Fig. 5.

Using a pulse-echo system, the backscattered spectrum from the grated surface at various angles of incidence were recorded. The backscattered spectrum for normal incidence is shown on Fig. 19. There are two distinct minima at 1.5 MHz and at 3.8 MHz. These anomalies are not easily explained. The Rayleigh velocity would produce on a free titanium component which is 1.7 MHz. The deviation may be due to several factors, e.g., nonflatness of the contact, induced stress, etc. The origin of the 3.8 MHz minimum on Fig. 18 is not clear at this point either. The forward scattering (180°) or through transmitted spectrum (obtained by a receiving transducer) shows also two frequency minima on Fig. 20 which we cannot explain. For non-normal incidence, scattering of both incident L waves and mode converted S waves (at the interface of the sample) are studied. On Fig. 21 the backscattered (pulse-echo) spectrum is shown for a 19° incident wave in water. Since this angle is above the longitudinal critical angle, a 43° shear wave enters into the titanium sample, this 43° shear wave in titanium is diffracted by the grating and different orders of diffraction maxima occur governed by the grating equation (Eq. 2). The diffraction maxima at 1.4 MHz and 2.8 MHz are obtained at 43° incident angle. This information can be used to evaluate the periodicity of contact at the diffusion bonded surface. For example, the measured maxima from Fig. 21 is used to calculate the periodicity as 1.78 mm which is in excellent agreement with the actual value 1.73 mm.

Fig. 19 Pulse-echo normal incidence spectrum from a corrugated diffusion bonded interface in titanium.

Penny-Shaped Crack with Periodically Rough Surface. The effect of the grating surface area on the diffracted field has been considered by scattering from a finite penny-shaped region (a crack) inside diffusion bonded titanium. On Fig. 22 the backscattered spectrum at normal incidence from the crack is shown photographed together with the reference spectrum. The minimum at 9.69 MHz is the frequency component corresponding exactly to the first diffraction order—produced along the crack (5 mm in diameter) having a periodicity of 330°—propagating with Rayleigh velocity on titanium. It appears that the anomalies in the frequency spectra are produced by finite periodic surfaces also. It should be interesting to find limiting conditions to obtain this anomaly, both in terms of dimension of the crack and dimension of surface conditions.

At oblique incidence backscattering the spectrum produced is shown on Fig. 23 which is obtained from the crack with a 53°L wave. The maxima at 12 MHz indicate that the periodicity of the surface is 330° which is in good agreement with the actual value of the periodicity 300°.

Fig. 20 Through transmission spectrum from a corrugated diffusion bonded interface in titanium.

Fig. 21 Diffraction pattern spectrum of an incident 43° shear wave from a corrugated diffusion bonded interface in titanium.

SUMMARY

In order to aid the understanding of the interaction of ultrasonic waves with periodic structures—frequently appearing in various materials—experiments were conducted to study ultrasonic scattering from interfaces with periodic structures. The interfaces between water and various solids such as stainless steel, duraluminum, polystyrene, and brass were studied. The solid-water (water backing on the periodic surface), solid-air, and solid-solid were also considered. In addition, ultrasonic scattering from periodic
surfaces inside diffusion bonded titanium was also studied. Two cases were discussed: (a) the periodic surface is large, and (b) the periodic surface is smaller (finite crack with periodic surface) than the beam. The periodic surface is a triangular shaped grating with periodicity ranging from 100μm to 1730μm.

Both narrowband and broadband experiments were conducted. From the angular and frequency dependence of the scattering the contacts between the two surfaces were accurately determined. A number of anomalies were observed in the backscattering spectrum (at normal incidence) in the form of sharp frequency minima. These missing frequency components (at m = 0, i.e., at the zeroth diffraction order) are first (m = 1) or sometimes higher diffraction orders coupled along the grating surface with velocity of sound in water and/or the Rayleigh velocity in the solid. Although no elastic wave theoretical analysis is available at present to predict these anomalies, electromagnetic and acoustic analogies to this problem have been treated by Lord Rayleigh. It is suggested that spectroscopic studies of scattering from periodic structures should be used as models for nondestructive evaluation of such problems as multiple defects, bonding between two or several layers, and fiber-reinforced composites.

Fig. 22. Pulse-echo normal incidence spectrum from a penny-shaped crack with corrugated surface.

Fig. 23. Diffraction pattern spectrum of a 53° L wave scattered from a penny-shaped crack with corrugated surface.

ACKNOWLEDGMENT

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REFERENCES

SUMMARY DISCUSSION

Bernie Tittmann, Chairman (Rockwell Science Center): The floor is open for questions.

Ross Stone [IRT Corporation]: I apologize if I’m asking an obvious question, but it strikes me that as you scan in frequency and for a fixed angular orientation of your transmitter, scanning your receiver in angle, the signal you build up is exactly proportional to the spatial Fourier transform of whatever the structure is. In other words, if you have a full spectrum of spatial roughness, you will get a full spatial Fourier transform. If one inverted that spatial full Fourier transform, wouldn't you get a picture of the roughness? Have you used that?

Laszlo Adler (Ohio State University): No, we haven't. We would be very interested in a fixed position of the transformer hitting it normally and looking at the back reflection.

Ross Stone: You chose the sample so that you only had one?

Laszlo Adler: It's not easy to have all the angular positions.

Ross Stone: I would suggest you try it. I think it might be successful.

Laszlo Adler: Thank you.

R.D. Weglein (Hughes): I wanted to make a comment that polystyrene is very similar to lucite. I made the same observation using the reflection acoustic microscope where we could measure what I call acoustic material, material based on the surface skimming bulk wave, longitudinal in styrene.

Laszlo Adler: The longitudinal angle, but you do not have a real angle for polystyrene?

R.D. Weglein: It's the angle for the longitudinal wave.

Laszlo Adler: I think the other component is not quite as intense as the general --

R.D. Weglein: That's because the reflection is strong, very strong, so the incident amount of energy that's transmitted and leaks into the surface is very small than it would be for a Rayleigh wave.

Laszlo Adler: I didn't say you cannot have a surface. You cannot have a Rayleigh wave generated on the polystyrene with the usual technique because you don't have a Rayleigh angle, but you can have a surface. I observed that, also.

Bernie Tittmann, Chairman: We will now move on to the next paper.