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SPECIAL ISSUE: ULTRASONICS

- Medical
- Gas meters
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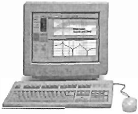

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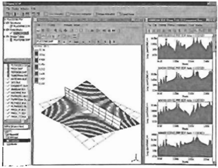

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From the President

Listening at the dawn of a new millennium...

Our recent "Acoustics Today" conference provided delegates with a poignant reminder of acoustic measurement and assessment as it has developed during the course of this century, and particularly the last fifty or so years. Anecdotes from the past were relived and past acousticians' instrumentation dusted off and brought to the conference as memorabilia. Members' achievements were noted and their efforts over many years were acknowledged.

Reflecting over my years in the field of acoustics and involvement in the AAS, I am reminded how this national society has served the wider community through its members in listening to and responding to many and varied acoustic issues, and our members' involvement in research and development in acoustics and associated fields.

It is evident from the papers presented over the years in our national conferences and ever increasing number of local and international conferences, as well as Acoustics Australia's informative articles, that our Society has also been at the forefront in advancing awareness of the significant progress in acoustics that has been made.

As we consider the challenges and listen to the new voices of the future millennium, we realise that to a large extent the members of the Society are becoming increasingly defined in terms of our involvement in a global exchange. Within our membership we have already embarked on addressing the challenge posed by landmines in Cambodia, we are researching traffic noise of once distant cities. Certainly the global village is encroaching on our shores, and increasingly calling on our expertise and field of speciality. Have we not witnessed the dream of Prof. Graeme Clark develop, as he and his researchers created the first muffled sounds for those whose listening was silence?

Listening at the dawn of the new millennium we will hear the hum of technology, we will sense the vibration of unseen speeds, and we will listen to the dreams of those who will dare to challenge the boundaries. I suspect this will not be all. There will remain the noise of the last millennium, the rumbling of traffic, the beat of unskilled musicians, and the clatter of disputing neighbours ... that will be work enough for all of us!

Thank you for the privilege of Presidency at this exciting time. Our councillors have been focussing on future directions at our recent council meetings and I will make a fuller report in the New Year outlining some of our ideas. Once again thank you for your support, and I take this opportunity to thank all councillors and Division office bearers for your efforts over the past year, and a particular thank you and a word of encouragement to Graeme Yates. We have sincerely appreciated the work and effort you have carried out for the Society through what has been a stressful period.

To all members of the Australian Acoustical Society:

Happy New Year!

Geoff Barnes
President

Editorial

Ultrasonics is an area of acoustics that is wide in its scope and growing in importance. Included are such relatively mundane areas as ultrasonic cleaning and ultrasonic welding, right through to the complexities of phonon propagation in crystals. The papers in the present special-topic issue address the middle ground of ultrasonic sensing and non-destructive testing. Here the fact that ordinary solids and liquids are moderately transparent to ultrasonic waves provides the background upon which the techniques are built, while the further fact that transmission properties are significantly modified by changes in density, elasticity or structure allows such changes to be detected and imaged.

There are further advantages to the use of ultrasonics in comparison with other possible techniques. Ultrasonic radiation at typical imaging intensities is harmless to biological tissue, which cannot be said of x-rays, and the millimetre-scale resolution is adequate for nearly all medical and industrial purposes. In addition, the low speed of sound compared with that of light makes the use of Doppler techniques straightforward for the measurement of liquid or gas flows in a variety of situations.

The four papers in this issue present some of these applications in detail - the propagation of ultrasonic waves in composite panels such as used in aircraft structures and the consequential detection of damage, the design of an ultrasonic gas-flow meter for domestic and industrial applications, the use of ultrasonics and medical imaging, and the support of these and other applications by measurement and calibration.

Obviously we have explored only a tiny fraction of the possible uses of ultrasonics in this issue, and we will follow up at a later time with papers on other applications. It is comforting to know that acoustics is a field so broad and so rapidly advancing that no simple inclusive survey of even a small part of it is possible!

The Editors

ULTRASONIC DOMESTIC GAS METERS

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ABSTRACT: Different ultrasonic domestic gas meters and the transducers used are discussed. They all measure a gas velocity with a transit time method. Time measurement techniques include repeated transmission and phase measurement. The propagation of the acoustic energy in the duct of the meter is in the form of modes and these can cause waveform changes and timing errors, which are discussed. The relationship of the velocity measured to the flow is not simple and various means are used to determine the flow from the velocity. The significance of delays and proper reciprocal operation is discussed.

1. INTRODUCTION: THE TASK OF A GAS METER

During the last few years there have been several ultrasonic domestic gas meters developed [1-8] and much activity in the patent literature. This paper attempts to explain some of the more interesting features of these meters and to draw together the many common threads that they have.

The purpose of domestic gas metering is to measure the heat used by the consumer and this is done by assuming that this is proportional to the quantity of gas. The ideal measurement of the quantity of gas would be its mass but it has traditionally been its volume; this assumes that the temperature and the pressure or their average values are known. The traditional diaphragm gas meter measures the volume of gas that passes through it by filling and emptying a bellows with the gas. The usual range of flows to be measured is from pilot flow of 15 L/h to 6000 L/h. Some capacity to measure flows outside this range is also needed. Pressure corrections are not usually done but sometimes a temperature correction is made to 15°C.

The ultrasonic gas meters that have been developed do not measure the heat of the gas nor its mass nor its volume but attempt to measure the volume flow rate by measuring a velocity in the flow. The relationship between the measured velocity and the flow rate is discussed later in this document. They are all sampling meters with a measurement being made every several seconds. They are called inferential meters because it is possible to infer the volume of gas that has passed by integrating the flow rate with respect to time.

All of the ultrasonic domestic gas meters developed so far are powered by lithium cells that usually operate for about 10 years. They need to function over a temperature range of at least -10°C to 50°C. The measurement uncertainty for most of the flow range is 1.5% but this is larger at low flows. The meters also need to work with a range of gases from air to methane.

2. TRANSIT-TIME ULTRASONIC GAS METERS

All ultrasonic domestic gas meters use a measurement of the transit-time of an ultrasonic pulse in a duct through which the gas is flowing to determine the velocity of the gas. The geometry of the duct varies so that sometimes the ultrasound is parallel to the flow and sometimes it makes an angle to it. In the latter case, it is the component of the flow velocity in the direction of the ultrasound that is measured. By measuring the times of travel of the signal upstream and downstream in the duct the velocity, v, can be calculated from the equation

$$v = \frac{L}{2}\left(\frac{1}{T_d} - \frac{1}{T_u}\right) = \frac{L(T_u - T_d)}{2T_d T_u} \tag{1}$$

where T_d is the time downstream, T_u the time upstream and L is the distance between the transducers. For the arrangement shown in Figure 1, of transducers in a tube of diameter 15 mm, the velocity of the gas at 15 L/h is about 20 mm/s and at 6000 L/h about 10 m/s.

The time for the pulse to travel the length of the tube is L/c where c is the velocity of sound. For a tube of 175 mm this has a value of approximately 500μs which is a typical value for most of the existing meters. The difference between the upstream and downstream transit times for a velocity of 20 mm/s is 57 ns so a resolution of a few nanoseconds is needed for reasonable uncertainty. To do this by direct timing using a fast clock is certainly possible but a lot of power is required to run such a clock. For a gas meter expected to operate from a battery supply that should last for ten years, this direct timing method is not feasible.

3. TRANSDUCERS

The main problem with transducers that must work in gases is that the acoustic impedance of the gas is much less than that of the transducer. This has been overcome in three ways. A traditional approach is to use a matching layer on the face of the transducer that has an acoustic impedance intermediate between the gas and the transducer material which is usually a piezo-ceramic. The materials that are suitable for this are very light composite materials that have to be specially made. To reduce the Q an absorptive backing may also be used [2]. The frequency of operation is usually about 180 kHz.

Another transducer used in some gas meters [3] operates at 40 kHz and uses a small loudspeaker cone attached to a piezo-ceramic element to couple to the gas. This transducer has a larger Q and so is not particularly suitable for impulse timing.

A third solution is the transducer developed by CSIRO/AGL [9] that uses a strip of metal coated, polyvinylidene fluoride (PVDF) film of 25 μm thickness and curved in a smooth "M" shape. The PVDF is prepared by poling and stretching to give it piezoelectric properties. The curvature assists some of the modes of vibration of the film when it is excited by signals applied to either side. The result is a transducer of low Q and with a frequency of 120 kHz, that operates with low voltage excitation and can be used either as a transmitter or as a receiver in a reciprocal manner. Due to the properties of the PVDF the output of the transducer depends on temperature and so the gain of the system must be varied to allow for this. An automatic gain control system is used in all meters to allow for the changes in the transmission properties of the gases, and changes in the transducers and electronics.

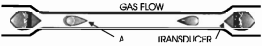

Figure 1. Transducers in a metering tube with mode control devices (A).

4. PROPAGATION OF ULTRASOUND IN DUCTS

When ultrasound propagates in a duct it generally does so as a series of modes. The exact nature of these modes depends very much on the geometry of the duct but they travel at speeds that depend on their complexity, with the simpler modes travelling the fastest. The plane wave is regarded as the simplest mode. Other modes have a cut-off frequency for the conditions involved, that is, they will not be propagated in a given duct below this frequency. Many modes can propagate in ducts that are somewhat larger than the wavelength.

The received waveform in a gas meter is due to the arrival of a number of modes and this has the effect of prolonging the arrival time of the signal. The signal is also prolonged by the natural oscillation of the transducer as an oscillator with a particular value of Q. It is thus to be preferred that the transducer have a low Q so that this effect is not enhanced. This long signal is of great significance to the pulse repetition timing method.

The modes also behave differently in the presence of flow and this leads to changes in the received waveform depending on whether it has been transmitted upstream or downstream. This change of waveform can have serious consequences for the timing of the signals as explained in the next section. The simple duct is usually modified to try to control these changes. An example of this is the device shown as "A" in Figure 1 [11]. Other configurations use an element down the axis of the tube [5]. Some designs use very small ducts that allow the propagation only of the plane wave mode [7]. This also has the effect of increasing the pressure drop across the meter since this varies as the inverse fourth power of the diameter of the duct. Some of this pressure drop may be able to be recovered since it is a velocity head and some meter designs [6] use a conical recovery section to do this. Sometimes the transducer is made considerably larger than the duct to try to avoid the generation of these modes [6].

5. WAVEFORM AND TRIGGERING

The time interval that needs to be measured is from the time of the excitation of the transducer to the arrival of the signal. The first is known very precisely but the arrival time of the signal is not. The reason for this is that the signal starts at a very low level as is shown in Figure 2. It is necessary to select some part of the signal capable of greater precision for the second timing marker. A zero crossing in the middle of the signal is suitable or a deliberately introduced phase reversal.

It is essential that the same zero crossing be chosen consistently for the timing as the time difference between one negative-going zero crossing and the next is far more than the uncertainty that is required in the timing. One common technique uses a comparator, one input of which is the signal and the other a reference or threshold level. The comparator produces an output when the signal passes the threshold. The next zero crossing (perhaps in a particular direction) can then be identified for the timing marker. To ensure that the correct zero crossing is chosen it is preferable to have a signal that rises rapidly. This means that a low Q transducer should be used. For a system that depends on selecting the same zero crossing in the waveform by its relation to peaks of particular heights, changes in the envelope of the received signal must be small. This is not so for propagation in a flowing gas.

This change in peak heights due to flow is illustrated in Figure 2 where two waveforms are shown. One is for transmission upstream into a flow of $4 m^3/h$ in a 15 mm diameter tube and the other is for transmission in the opposite direction. They have been adjusted to have the same peak height. The individual peaks in the two waveforms have quite different heights however, so that a threshold, such as represented by the thick line from the left, and a comparator combination would select different zero crossings. The upstream waveform is almost the same as the zero flow waveform but the downstream can be very different. Because of the flow profile the wavefront bends to the outside giving a pumping of the (0,2) mode. This is also seen when the tube wall is colder than the gas. The exact effect depends on the phase relationship between the plane wave and the (0,2) modes. Sometimes the second part of the waveform can be larger than the first with obvious detrimental consequences for the triggering and selection of a particular zero crossing.

6. TIMING

The timing of the signal in the two directions must be done with an uncertainty of about 3 ns if the specification is to be met for the uncertainty at low flow rates. This is quite difficult to achieve when the restriction of low power consumption is applied. A timing clock of even 10 MHz will allow direct timing to only 100 ns. An advantage is the very large number of measurements made in the billing period. If these measurements are truly random a high single measurement uncertainty can be tolerated while still achieving a low uncertainty in the mean value. The meters developed so far do not rely on this averaging to achieve their required uncertainty.

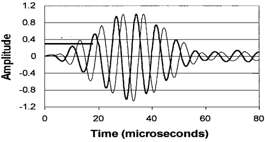

Figure2. Received waveforms from transmission downstream (heavy trace) and upstream (light trace) made to have the same maximum value.

6.1 The pulse repetition technique

In this technique [4], a low frequency clock is used and the time to be measured is increased by sending the signal down the tube a number of times. A timer is started as the first pulse is sent down the tube. When it arrives it is detected and another pulse is immediately sent down, in the same direction, and so on for, say 100 pulses. When the 100th pulse arrives the timer is stopped. Thus the time that is measured is 100 times that for one pulse and so a clock frequency 100 times less may be used. This works well and allows resolutions of a few nanoseconds with a clock period of 100 ns. There are, however, some drawbacks as detailed in section 7.

6.2 Phase techniques

Another method [8] of timing uses a special drive signal of 24 cycles of sinusoid waveform with a phase reversal built into it two thirds of the way through. The drive signal is generated from the 1.44 MHz clock by counting down to 180 kHz so that it is phase locked to it. Members of a group of eight capacitors are switched in turn by the clock to sample the received signal. During the 16 cycles before the phase switch they form a good average of the incoming waveform. A phase detector is used to compare the incoming wave with this average and hence the reversal is detected and the sampling stopped. This measurement establishes the time to one clock pulse but this is not nearly accurate enough. The phase of the stored waveform on the capacitors is then investigated. The voltage on each of the eight capacitors is read by an analogue to digital converter. If the phase reversal stopped the data collection at exactly the start of the phase of the received signal then the received signal and the driving signal (and the clock) would be in phase and an integral number of clock pulses would correspond to the transit time to be measured. Usually there is a phase difference that needs to be determined by the curve fitting procedure used. It is claimed that this can be done to one thousandth of a period of the signal thus achieving an accuracy of several nanoseconds.

In a similar technique [3], the transducer is excited with a tone burst of 8 cycles at 40 kHz. The received waveform is sampled at 320 kHz to give the data set $y(t_i)$. The phase is given by

$$\phi = \tan^{-1}\left[\frac{\sum_{1}^{n} y(t_i)\sin(2\pi 40{,}000 t_i)}{\sum_{1}^{n} y(t_i)\cos(2\pi 40{,}000 t_i)}\right] \qquad (2)$$

which is more easily calculated than might appear since the sine and cosine values for eight samples per period are constrained to be either zero or ±1 or $\pm 1/\sqrt{2}$. It can only be determined between 0 and 2π. To remove the phase ambiguity (or to do "phase unwrapping") a separate direct measurement of the time of flight is done using a threshold and comparator method with single pulse excitation of the transducer.

6.3 Clock period interpolation

A portion of the received waveform is digitised at a rate equal to the clock rate and these data are stored. If timing is done to a zero crossing it is easy to find the integral number of clock pulses that finish just before that crossing. Then an interpolation is done to determine that fraction of a clock period to the crossing.

It is also possible to interpolate by using a fast voltage ramp lasting one clock period with a circuit that samples this voltage at the instant of the event being timed. The voltage sampled divided by the maximum voltage for the ramp, is the fraction of the clock period required.

7. PULSE-REPETITION TECHNIQUE PROBLEMS

This technique enables timing to be done with sufficient precision but it introduces some additional problems that have to be dealt with before a satisfactory meter can be made. In the graph of Figure 3 the velocity measured by the meter has been fitted to a straight line and the differences from this line have been plotted against the flow rate. There are systematic cyclical variations from the straight line. The reason for this behaviour lies in the manner of propagation of the acoustic pulse in the duct. Because it travels fastest the plane wave mode arrives first at the receiving transducer but during the reception of the second signal the modes from the first transmission, that travel at half its speed, will also be arriving.

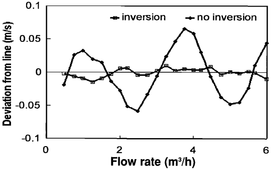

Figure3. Cyclical deviations from the line of best fit.

During the reception of the third plane wave pulse the modes of one-third speed from the first transmission and half speed from the second transmission will be simultaneously arriving, and so on.

The timing of the pulses is done using a zero crossing and the presence of another signal can change the exact time of this crossing. This would not matter much if everything stayed constant but the flow changes the phase relationship of the modes to the plane wave. For example for downstream propagation, the velocity of the gas increases the effective velocity of the mode to $c_m + v$ and the change in arrival time, ΔT, is given by

$$\Delta T \approx \frac{Lv}{c_m^2} \quad (3)$$

where c_m is the velocity of the mode. The value of ΔT varies with flow from 0 to many times the period of the signal and so there is a cyclical effect on the timing error. This is the cause of the oscillation seen in Figure 3.

If a particular mode interacts with the plane wave mode to shift the time of a particular zero crossing by $\delta\tau$ then if we could invert the plane wave mode the time shift would be $-\delta\tau$. If we could add these two errors, they would cancel. This can be arranged to happen since we are able to transmit both normal and inverted pulses. It is, however, not quite straightforward because we would like to cancel the effect of more than just one mode. The principles on which the error cancellation scheme works are:

- a timing error occurs when the main signal is combined with a much smaller signal (slower mode),
- this error has the same magnitude but opposite sign if either the main signal or the smaller signal, but not both, are inverted,
- the error has the same magnitude and sign if both are inverted,
- the principle of superposition applies, that is the signals act independently in the presence of each other.

The error in the timing can be cancelled if we can generate equal numbers of errors of opposite sign. This can be achieved by transmitting an inverted pulse once in every four transmissions. A more detailed explanation of this scheme is in [10]. It is able to correct substantially for the timing error caused by the slow modes in the tube with the result shown in Figure 3.

8. THE RELATIONSHIP OF VELOCITY TO FLOW

The meter calculates the velocity of the gas, but exactly what velocity is this? In a duct of flowing gas there is a range of gas velocities forming what is called the flow profile. For laminar flow the velocities form a parabolic shape, for turbulent flow this flattens, and the exact shape varies with the Reynolds number. The maximum Reynolds number for most of the gas meters is about 10,000 and turbulent flow is normally regarded as occurring for flows with Reynolds numbers above 2200. Thus the meters span the two flow regimes of turbulent and laminar flow. The maximum velocity v_{max} for both cases is that along the axis. The mean velocity for laminar flow is $0.5v_{max}$ and approximately $0.75v_{max}$ for turbulent flow but in this case the exact relationship varies with Reynolds number.

It has been shown [1] that a plane wave can sample equally over the whole diameter of the tube and so the velocity calculated from the transit times for a plane wave is the mean velocity of the gas. Usually there are other modes present, however, and these will sample preferentially from different parts of the cross section of the tube. The extent of this error depends on the relationship of the wavelength to the tube diameter. If the tube is large compared with the wavelength rather than filling the tube the ultrasound travels down the centre in a beam-like manner. In this case the velocity obtained will be closer to v_{max} and will thus have a different relationship to the mean velocity depending on whether the flow is turbulent or laminar.

For the CSIRO/AGL gas meter measurements of the mean flow and the velocity show that the velocity measured is closer to the mean than to the maximum velocity. The ultrasonic signal used is of sufficiently large wavelength compared with the diameter of the tube that it tends to spread. Experimentally the ratio of the slopes of the lines of best fit for velocity versus flow in the turbulent and in the laminar regions is 0.989 whereas the ideal value would be unity. If the velocity measured were that along the axis, the result would be approximately 1.5. A velocity dependent correction algorithm is used to reduce the error.

An alternative technique to produce a better average over the velocity profile is to use a beam-like signal but to direct it across the flow profile. Sometimes this is done in a circular duct with a diagonal crossing but in a commercial version [2] of this type of meter, the duct is rectangular with the long side about five times the length of the short side. As shown in Figure 4 the beam is reflected in a "W" shape from the sides of the duct using a special reflector in the middle to refocus the beam. There is a quarter wave plate to avoid the "V" reflection.

9. RECIPROCITY AND DELAYS

The time for the transmission of a pulse of ultrasound in the tube when there is no flow present should be the same in both directions. For this to happen the time delays for the transducers in the presence of the medium must act with identical delays whether they are acting as transmitters or as receivers. According to the reciprocity theorem in acoustics the transmission properties will be independent of the transducers and the properties of the medium if the transducers are linear and if the impedance of the circuit that the transducers are connected to is zero, or alternatively infinite. Whilst strictly speaking, neither of these conditions can be met in practice, it is possible to use impedances sufficiently low to achieve the required degree of reciprocity. It is also desirable to have the transducer see the same impedance whether it is transmitting or receiving. Linearity in the transducers is a significant requirement since they operate with very different signal levels when they are transmitting to when they are receiving.

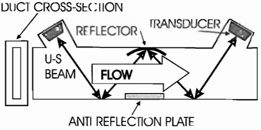

Figure 4. Rectangular cross section duct with "W" acoustic path.

Because the difference in transmission times between the two directions must be small when there is zero gas flow, it is important that the circuits used for upstream and downstream transmission do not differ in their time delays. The time difference, that is the maximum that is acceptable, is 2 ns. For a signal of 130 kHz when a zero crossing is used for timing, this corresponds to a phase stability of 0.1° which for two separate amplifiers working over a wide temperature range is hard to maintain. It is better to have as many parts of the circuit in common as possible, to avoid the time delay differences that lead to a poor measurement of the zero velocity.

The transit time measurements at zero flow may be equal but still in error because of electronic delays and delays caused by the transducers by an amount ΔT. Then there is an error in the measured velocity of $2\Delta T/T_0$ where T_0 is the transit time in still gas. This would not be serious if it remained constant but the value of T_0 varies with the gas type and the temperature. For ΔT of 2μs this gives an error of about 1%. Due to a change in the velocity of sound from air to hot gas, this will change by about one quarter giving a change in the measurement of 0.25%.

A means to eliminate the delays caused by the transducers and associated electronics is to use the second form of equation (1) that has the term T_u-T_d in the top line. This difference cancels the delays. The bottom line contains the term $T_u\ T_d$ and this does not eliminate the delays. However, this can be written as

$$T_uT_d = \frac{L^2}{c^2(1-v^2/c^2)} \qquad (4)$$

so that a knowledge of the velocity of sound, c, and an approximate knowledge of v enables it to be calculated quite accurately since v/c is small. The velocity of sound is found from a separate measurement using a third transducer [8] or a peripheral signal from the gas velocity measurement transducers [6]. This measurement is based on multiple reflections using only time differences that cancel the delays.

10. CONCLUSION

Domestic ultrasonic gas meters face problems due to the requirement for small size and low power consumption. The various techniques used to achieve the operational specifications needed have been described. The acceptance by the market of these devices has been limited to the United Kingdom and there it has been muted due to the higher cost of manufacture of the meters compared with the traditional diaphragm meter. An electronic meter permits several billing rates for different times of the day and has the inherent advantage of allowing easy communication with the outside world to report consumption or fault. These features have not yet become important in the market. As the cost of their production continues to fall and with the increasing move towards integration of billing systems for water and energy reticulation it seems that they will be more used in the future.

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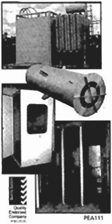
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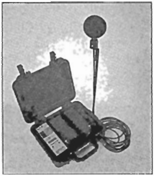

THREE-DIMENSIONAL MEDICAL ULTRASOUND

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ABSTRACT: A number of groups around the world are working in the field of three dimensional (3D) ultrasound (US) in order to obtain higher quality diagnostic information. 3D US, in general, involves collecting a sequence of conventional 2D US images along with information on the position and orientation of each image plane. A transformation matrix is calculated relating image space to world space. This allows image pixels and region of interest (ROI) points drawn on the image to be displayed in 3D. The 3D data can be used for the production of volume or surface rendered images, or for the direct calculation of ROI volumes.

1. INTRODUCTION

The purpose of this paper is to briefly introduce the reader to the field of three dimensional medical ultrasound. Ultrasound, as a medical imaging modality has developed since the end of the second world war, and grew out of developments in SONAR (SOund Navigation And Ranging). Ultrasound images from within the body are effectively 'sonar maps'. Ultrasound is used extensively in medicine, especially in obstetrics (care of the unborn baby), gynaecology and cardiology. Ultrasound examinations now account for at least 25% of all of medical image examinations.

Ultrasound images are tomographic in nature, i.e. they provide a cross-sectional images of patient anatomy. In this they are similar to X-ray computed tomography (CT) and magnetic resonance (MR) images. However, ultrasound does have significant advantages over CT and MR, for example, ultrasound is inherently safer than CT or MR, especially when imaging the fetus. Also, US machines are many times cheaper to purchase and maintain than CT or MR machines.

2. TWO DIMENSIONAL ULTRASOUND

Before we can discuss 3D ultrasound, we need to briefly describe the formation of 2D images. Images are formed by measuring the time for echoes to return from inside the body and therefore are sometimes called 'echograms'. Sound is reflected back towards the transducer wherever a change in the acoustic impedance is encountered. Conventional 2D images are produced by the emission of ultrasound pulses from an array of piezoelectric elements. The time for echoes from inside the body to return to the transducer elements is recorded and the depth of echogenic structures calculated assuming a velocity of sound of 1540 m/s in tissue.

Medical ultrasound probes typically operate in the range 3 - 7 MHz. The maximum resolution of course depends on the wavelength of the ultrasound. The wavelength of 3 MHz ultraound is about 0.5 mm in tissue. Axial resolution is given as half the spatial pulse length. For example, if a 3 MHz probe emits pulses four cycles in length, the axial resolution will be $(4 \times 0.5 \text{ mm})/2 = 1.0$ mm. Attenuation increases with frequency, therefore there is a trade-off between resolution and depth of penetration.

3. THREE DIMENSIONAL ULTRASOUND

3D ultrasound is a logical extension of 2D ultrasound, and a number of groups around the world are currently working in the field of 3D ultrasound (for a comprehensive review see Nelson and Pretorius 1999). 3D US involves acquiring a sequence of conventional 2D ultrasound images through a volume of interest (VOI) within the body. Some means is required to register the acquired images to a three dimensional coordinate system. This can be achieved by means of a 3D tracker connected to the ultrasound probe, or by a rotational or translational mechanism within the probe housing that sweeps the image plane through the VOI (Hamper et al, 1994, Gilja et al, 1995, Blaas et al, 1995). The two methods are depicted schematically in figure 1.

Transducers with an internal mechanism tend to be quite bulky and have to be held stationary for a number of seconds to allow a sufficient number of images to be acquired. Probes with an external localiser attached can be scanned free hand. An advantage of 'dedicated' 3D probes is their compactness—no external localiser is required. However, a disadvantage of dedicated 3D probes is that they have a narrow field of view close to the surface of the probe and also cannot capture extended structures (blood vessels in the leg, for example). In contrast, transducers with an external localiser can be used to capture extended structures.

3D image sequences can be acquired from within blood vessels using an intravascular ultrasound probes (Ennis et al, 1993, Rosenfield et al, 1992). This is effectively a very small array of piezoelectric elements on the end of a narrow tube (catheter) that can be inserted into an artery. The catheter is pulled back at a constant rate and images are acquired at regular intervals in time and therefore position. In this case it is assumed that tip of the catheter has moved in a straight line down the centre of the lumen. Rotation of intravascular probes has also been tried, in which case rotation angle is used to determine image orientation (Kok-Hwee et al, 1994).

Martin et al (1993) have developed a 2D phased array probe small enough to fit down an oesophageal catheter. The probe is deployed adjacent to the heart, providing clear images through the chambers. A pulley system sweeps the image planes through the heart, enabling cardiac volumes to be obtained during anaesthesia.

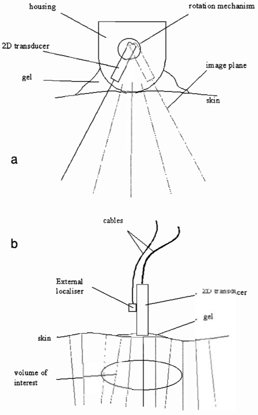

Figure 1. Different techniques for acquiring a 3D image dataset. (a) In a dedicated 3D probe some kind of mechanism rotates or translates a conventional 2D probe. (To improve clarity, only a few image planes are shown). (b) Free hand acquisition of images.

Many different types of external space trackers have been used to record the position and orientation of ultrasound probes. The most commonly used are electromagnetic (EM) devices, for example those manufactured by Polhemus Inc, 3Space Fastrak (Gardener et al, 1991, Hodges et al, 1994, Hughes et al, 1996, Blass et al, 1999) and the Ascension Technologies Flock of Birds (Leotta et al, 1997, Gilja et al, 1998, Berg et al, 1999). These have a transmitter and receiver each containing three orthogonal wire coils. The transmitter coils are energised giving rise to signals, which are detected by the receiver coils. The relative strengths of the field picked up by the receiver enables the position and orientation to be calculated relative the coordinate system of the transmitter. The transmitter and receiver connect to a systems electronic unit, which usually interfaces to a PC via a RS 232 serial connection (although Ascension Technologies produce a system (pcBIRD) that plugs into a PCI bus in a PC).

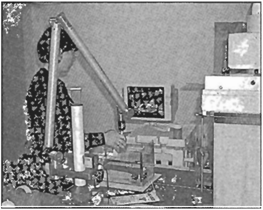

Figure 2. Mechanical Faro Arm attached to a 2D ultrasound transducer (a water-filled plastic test object is seen in the water tank).

EM trackers are prone to interference by nearby metal, in the case of the Polhemus Fastrak, studies have shown that this is minimal if the receiver is at least 7 cm away from the probe and 20 cm above a metal framed patient couch (Gardener et al, 1993). The flock of birds sensor can be attached directly to an ultrasound probe with no ill effects.

Mechanical arms have also been used (Sawada et al, 1983). Figure 2 shows a Faro Arm part of a system being developed by the author to quantify organ movement for radiotherapy purposes. Although mechanical arms are very cumbersome compared to EM trackers, they do have the advantage that they can be used in the presence of large quantities of metal, near a radiotherapy linear accelerator, for example.

Some groups have experimented with acoustic trackers comprising spark gaps placed on a structure attached to the ultrasound transducer and microphones placed on a stationary bar (Levine et al, 1989). These systems are fairly cumbersome and require the continual monitoring of temperature and humidity, which affect the velocity of sound in air.

There is a third method used by some companies in which there is no direct "localiser" but the operator does a freehand sweep of the scanning probe over the area of interest. The machine assumes a uniform movement and uses some image processing techniques to "stitch" the 2D scans together, in sequence, into a 3D data block

4. CONVERTING POINTS FROM IMAGE TO REAL WORLD COORDINATES

Central to any 3D US system is an algorithm to convert the coordinate of a point in a 2D US image (either an ROI points drawn on the image by the user, or a pixel) into world coordinates. The tracking device will give the spatial coordinates and orientation of the moving sensor relative to the device coordinate system (for the Faro Arm shown in figure 2, the origin of the coordinate system is the metal ball to the left of the base).

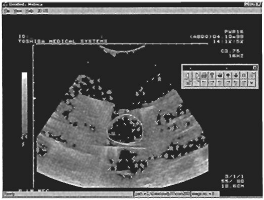

Figure 3. Ultrasound image through test object.

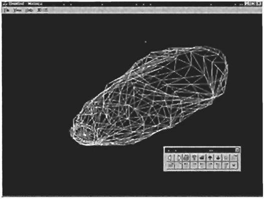

Figure 4. 3D reconstruction of test object as a triangle mesh.

The centre of the sensor is connected to a reference point in the image (for example the centre of the transducer face) via a series of 3D vectors. These vectors can be used to construct a (3 × 3) transformation matrix to convert points from image to world space (and vice versa if necessary). Calculation of the transformation matrix can be automated by scanning a test object of known dimensions.

5. ACQUISITION OF IMAGES

All ultrasound machines have a video output (for an auxiliary monitor for example), and so images can be acquired by a PC based video frame grabber. Dedicated 3D systems tend to use the video data available within the ultrasound machine. Ideally, the position and orientation data should be acquired at the same instant as each image. In reality there will be a small delay, which might need to be taken into account.

The number of images acquired and scan technique depends on what kind of processing is to be performed on the images. If volumes are to be calculated then only a few images, 10-20 for example, are required to adequately sample the structure or organ. Regions of interest (ROI) are traced on the relevant images (figure 3) and the points transformed from image space to world space. The multiplanar ROIs can be used to calculate volume directly, or the ROI points can be connected into a triangle mesh (figure 4) prior to volume calculation. For volume measurements, it is best if the acquired image planes do not intersect as many volume calculation algorithms presume non-intersecting ROI planes.

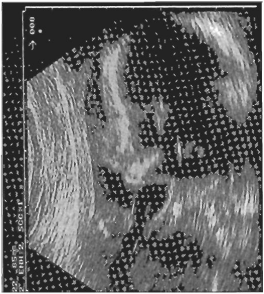

Figure 5. 2D ultrasound image through a fetal face.

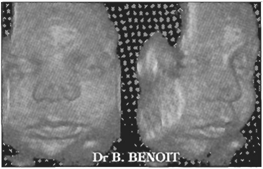

Figure 6. Surface rendered fetal face (not the same fetus as shown in figure 5). (Courtesy of Dr. B. Benoit).

If volume or surface rendering of the 3D image data is to be performed then many more images need to be acquired—in some cases as many as 10,000 (Barry et al, 1997). When very long sequences are acquired some means of removing the effect of cardiac and respiratory movements. Barry et al. have developed a system for quantifying plaque thickness in carotid arteries (the blood vessels that carry blood up the neck to the brain). Around 10,000 2D ultrasound images are stored on video tape. The audio channels are used to store the position and orientation data and ECG data (for cardiac gating). Images are digitised by computer after acquisition. Maybe in the future it will be possible to store this amount of video data directly onto a computer hard disc or RAM.

After the image data has been captured the next stage is to consolidate the data into a regular grid. A regular 3D grid is constructed, and a pixel intensity calculated for each node by interpolating between image pixels proximate to the node. Either a surface extraction algorithm can be applied to the data, or rays cast through the data to produce a volume rendered image. Surface rendered images can be used to calculate volume (assuming that a closed surface is generated). In spite of their name, volume rendered images cannot be used to calculate volume. Figure 5 shows an example of a fetal head in profile and figure 6 shows a surface rendering of a fetal head (although not the same one as in figure 5).

6. VOLUME ALGORITHMS

Prior to the advent of 3D ultrasound, organ volumes were calculated from maximum dimensions obtained from roughly orthogonal 2D images. These dimensions would then be used to obtain an ellipsoid volume. As can be imagined, significant errors arise if the organ is not nearly ellipsoidal in shape.

A number of different algorithms have been devised for calculating volume from multiplanar ultrasound images. Watanabe (1982) has developed a system, which utilises only multiplanar ROIs. The area of each ROI is multiplied by what we might term a local slice thickness. This technique is commonly used for calculating the volume of a structure imaged using X-ray computed tomography (CT) or magnetic resonance (MR) which produce parallel images of a precise and known spacing. In the case of images acquired using a hand held probe, images will not be exactly parallel and will not be exactly evenly spaced (as shown in figure 1b for example).

If the surface of an organ is tessellated into triangles, truly 3D volume algorithms can be used. For example a central point within the object can be connected to each triangle vertex to fill the space with tetrahedra (the volume of which are given by one sixth of the scalar triple product of the edge vectors connecting the centroid to the triangle vertices. This technique assumes that there is a clear line of sight between the centroid and each triangle vertex (i.e. does not have deep concavities). If the object is more complicated in shape, then tetrahedral decomposition can be performed within successive pairs of ROIs (Cooke et al, 1980).

An adaptation of Gauss' theorem (Hughes et al, 1997) can also be used. This involves multiplying the x, coordinate of each triangle centroid by the x component of the triangle normal and then by area of the triangle. This is repeated for the y and z centroid and normal components. The three volume calculations are then weighted according to the area of the surface projecting in the x, y and z directions respectively. Studies have shown that volumes can be measured to an accuracy of down to 2% (Hughes et al, 1996).

7. DOPPLER

When an ultrasound pulse reflects off a moving structure, a red blood cell (RBC), for example, it undergoes a shift in frequency. The magnitude of the frequency shift depends on velocity of the RBC relative to the ultrasound beam, and the sign of the shift depends on the direction of blood flow relative to the ultrasound beam. A colour image can be produced, overlying the grey scale anatomical image, showing variations in blood flow. If a sequence of registered 2D Doppler images is acquired then a 3D map of blood flow can be generated (Pretorius and Nelson, 1992, Picot et al, 1993).

8. THE FUTURE

A lot of work is currently being carried out to assess the advantages of 3D ultrasound compared to 2D (for example, Hamper et al, 1994). Some studies have already shown that 3D US is better able to detect fetal abnormalities such as cleft lip and palate (Ulm et al, 1999). Another advantage is that patients and non ultrasound literate medical staff are able to comprehend 3D images better than 2D US images.

Work is underway to develop 3D phased array probes. 2D phased array probes are commonly used in cardiac imaging. A linear array of piezoelectric elements is excited in a certain temporal pattern resulting in ultrasound beams propagating away from the face of the probe at various angles. An advantage of a phased array probe is that the field of view at depth is very much wider than the face of the probe. Hence it is possible to image the heart via the space between the ribs. If the linear array of piezoelectric elements is extended into a 2D array then we have a 3D phased array probe. However, 3D phased array probes have the same limitations as mechanical 3D probes, i.e. restricted field of view, especially close to the transducer. At present there are difficulties in developing viable 3D phased array probes. The major problem is one of bandwidth—i.e. all of the returning echoes cannot be processed quickly enough. Cross-talk between the closely spaced elements is another problem.

One can perhaps envisage a kind of mat placed across the abdomen of a patient that has a number of piezoelectric elements embedded within. The associated electronic circuitry would be able to process return signals in parallel thus producing a real-time 3D image of patient anatomy. Developments in 3D ultrasound rely on improvements computer technology.

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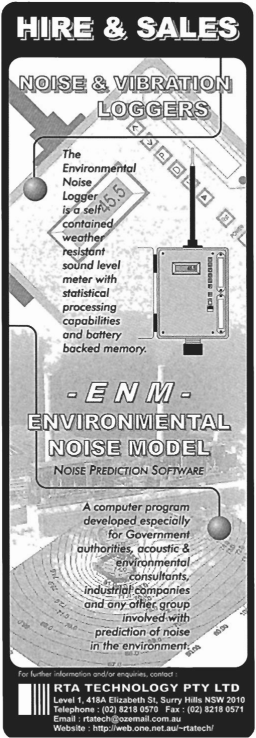

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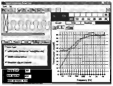

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ULTRASOUND CALIBRATION AT THE NATIONAL MEASUREMENT LABORATORY.

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Ultrasound Standards, National Measurement Laboratory
Division of Telecommunications and Industrial Physics, CSIRO Lindfield

ABSTRACT The National Measurement Laboratory (NML) has had interactions in ultrasound ranging from the medical (therapy and diagnostic), non-destructive testing/evaluation (NDT/E) to high power cleaning and sonic processing. A present emphasis is in therapy ultrasound. In this area there is a problem with poorly calibrated ultrasound therapy machines either delivering a dangerous amount of ultrasound or so little that it is of no clinical benefit. A traceability chain is required from the clinical user of the ultrasound therapy machine to national standards. A portable power standard (PPS) is presently being designed to enable the traceability to occur. Just as importantly the associated advisory publications are being formulated to enable its deployment in the traceability chain. The next major effort in ultrasound standards is expected to be NDT/E for Australian and New Zealand industry. A review of what is required for standards support in the NDT/E community is to be undertaken.

1. INTRODUCTION

Ultrasound is sound at a frequency greater than the audible (>20kHz), with the upper limit presently being constrained by technology to approximately 100 MHz. Power levels can be substantial, to some kW, with some hundreds of MPa of pressure. These large ranges in frequency and power indicate that there is a very broad range of applications for ultrasound.

In the Australian medical community, ultrasound has a strong presence:

- 14,000 registered physiotherapists use therapeutic ultrasound.
- 10% of the Australian population in one year have a diagnostic imaging ultrasound examination and virtually all unborn children are examined with ultrasound.
- Approximately 7,000 people per year in Australia are treated with lithotripsy for kidney stones, gall stones and the like.
- Countless surgical ultrasound units and dental descalers are in use.

For non-destructive testing/evaluation (NDT/E) of large and small mechanical plant, building and road structures, and aerospace components, the use of ultrasound is commonplace.

In the military, submarine warfare is heavily dependent on sonar technology. The same technology is also seeing applications in marine biology research.

Finally there are an increasing number of industrial processes being developed that make use of "high power" ultrasound to impart physical and chemical changes.

Metrology wise though, ultrasound is a comparatively new area. Many of the measurement techniques and standards are still in a high rate of evolution. The effort at the National Measurement Laboratory (NML-CSIRO) is even more recent.

The efforts of the ultrasound standards group at NML in recent years has focussed on:

- commissioning equipment and techniques to a level where useful standards measurements can be made,
- reviewing what is required for standards support in the ultrasound communities of Australia and New Zealand,
- commencing efforts to support the users of therapy ultrasound.

This paper will review the present state and future plans for ultrasound standards at NML and for the ultrasound community. The NML facilities will first be briefly described, followed by a more detailed description of the present efforts being directed towards therapeutic ultrasound and then the other areas of present and future interest. The therapy ultrasound effort has also been quite instructive in how to approach an area requiring measurement traceability as well as a more accurate and precise application of its particular technique or technology.

2. NML FACILITIES

Absolute Fundamental Standard

There are three fundamental quantities of interest for a propagating ultrasonic wave. These are the displacement and the frequency of the wave and the spatial distribution of the wavefront. The displacement and frequency can be measured absolutely using a path length stabilised He-Ne Michelson interferometer. The absolute displacement measurement is derived from the 632.8 nm wavelength of the laser, whilst the absolute frequency is obtained by comparison with the NML in-house atomic clocks. The fundamental standard Michelson interferometer is presently capable of a bandwidth of 0.1 to 50 MHz and a displacement resolution of 0.05 nm. There are only a handful of such absolute ultrasound standards operating in the world, all of which are resident in national standards laboratories.

In practice, the interferometer is commonly used to calibrate a secondary standard membrane hydrophone which is immersed in water and subjected to a well-characterised ultrasound field. The secondary standard is then used to calibrate client hydrophones for ultrasonic pressure sensitivity with respect to frequency. Occasionally, the interferometer is used to measure the ultrasonic displacement directly on a transmitting transducer in air or water and on solids which have an ultrasonic field excited within them.

Scan System

The other property of fundamental interest is the spatial distribution of the ultrasound field. This is often required when determining the ultrasound beam profile of transmitting transducers or the angular directivity of hydrophones (receivers). A sophisticated positioning system, more commonly termed a scan system, is used to accurately move the transducer about the ultrasound field. The scan system has the following features:

- Six degrees of freedom with a single manipulator.
- XYZ motion of 1000(400(400 mm with 1 μm resolution,
- Three angular motions of ±165°, ±100° and ±10° with respective resolutions of 0.001°, 0.01° and 0.05°.

NDT/E scans using pulse-echo transducers can be done on test pieces that are commonly used in testing work.

The scan system at NML will be calibrated using optical interferometry so that its spatial measurements are traceable to national length and angle standards. It will be the highest specification scan system for any ultrasound standards laboratory in the world. However, large defence and civilian NDT/E testing laboratories often have scan systems with specifications that are tighter by a factor of two.

Total Power Standard

Ultrasound transmitting transducers operating at higher powers will produce an ultrasonic field that exhibits a strong radiation force. This radiation force can be measured by directing it against a 45°, air-backed cone connected to a sensitive mass balance. The total ultrasonic power in the transducer's beam can then be calculated from the radiation force. The mass standards used to calibrate the mass balance are traceable to NML in-house standards. This power measurement device is typically termed a radiation force balance. The one used at NML has a bandwidth of 0.1-10 MHz and a power range of 0.1 to 30 W.

Miscellaneous

A range of standard, medical, NDT/E and industrial transducers are kept in order to produce a range of ultrasound fields and to undertake informal comparisons with other national standards laboratories. NML will participate in two formal international CIPM comparisons of ultrasound standards in the next 1-2 years. One will involve the measurement of hydrophone sensitivity and the other the measurement of ultrasound power at therapy levels. The latter comparison is particularly timely given the current effort in therapy ultrasound at NML.

3. THERAPY ULTRASOUND

The Problem

An ultrasound therapy machine typically consists of a high frequency generator driving a piezoelectric disc encapsulated in a metal housing which is then applied to the skin of the patient through a coupling gel or water bath. Clinical therapy ultrasound machines operate in the frequency range 1-3 MHz with a power range of 0-15 W or an intensity of 0-3 Wcm^{-2}.

The clinical users are commonly trained and registered physiotherapists. Ultrasound is one of the most common electro-physical therapy modalities used by physiotherapists. Some examples of medical conditions it is used to treat are sporting and repetitive strain injuries, rheumatiod arthritis, nerve pain, circulatory disorders, and deep scar tissue.

It has been estimated [1] that there are approximately 7,000 registered clinical users of therapy ultrasound machines per 10 million population in the western world. The widespread use of ultrasound is reflected in the extensive literature, eg [2-6]. Although ultrasound therapy is widely used, it is difficult to obtain a written clinical protocol [7, 8]. In a common teaching text [8] and a general literature review [9], the authors admit that there is a lack of controlled clinical trials to ascertain optimum treatment parameters.

It could be the lack of calibrated machines in clinical use that is contributing to the vagaries in clinical application of this therapy. Twelve surveys of the calibration of therapy machines have been conducted between 1973-95 in Australia, Canada, the Netherlands, New Zealand, United Kingdom, and the USA [10-21]. From these surveys, several features were clear:

- On average 70% (range 50-80%) of machines failed the standard applicable in that country. The allowed power inaccuracy is ±30% (sometimes ±20%).
- Regular calibration checking of ultrasound therapy machines was required.

It has only been in New Zealand (NZ) that a comprehensive follow-up survey has been done after corrective action. The 1985 NZ survey of 230 machines found that 65% had a maximum output that differed by more than (30% from that indicated [15]. Following this poor result, the NZ Society of Physiotherapists Private Practitioners' Association instituted a voluntary accreditation scheme for hospitals and private practices. The follow-up survey 10 years later [21] was encouraging in that only 18% of the machines failed (c.f. 65%). However, this is for a measurement that is made at full power as is commonly stipulated in IEC standards [22]. Disturbingly, it was found that 50% did not give the correct value over their full output range. Furthermore there was no correlation between calibration accuracy and period of use (hours of service) or the calendar period since the last calibration check. In NZ, routine testers are under no requirement to have their proficiency in testing examined; common practice in the western world. The NZ study suggests [23] that some machines cannot be calibrated properly, and/or may be incorrectly calibrated at manufacture. Furthermore, subsequent calibrations performed during its clinical life may be in error.

Anecdotal tales of patient discomfort or injury due to ultrasound therapy exist, but are seldom made widely known for reasons involving malpractice and liability. It was documented at an Edinburgh, UK, hospital recently that two patients did receive injuries due to treatment from a faulty and un-calibrated machine [20-22, 24, 25]. The alternate situation is no effective treatment. The NZ surveys [15, 21] showed that 4-7% of machines were either delivering no ultrasound or less than 10% of what was indicated (clinically ineffective). It is clear that in this situation the patients are paying for treatment and receiving none.

Conclusions

The western world countries covered by this short analysis all have very similar protocols for clinical use of ultrasound therapy and technical performance standards for the ultrasound therapy machines. The findings in each country can be amalgamated to make a number of conclusions:

- Therapy ultrasound is widely used but poorly applied clinically.
- International surveys have shown that there is an enormous calibration fail rate.
- Calibrations performed by routine testers who have not been proficiency tested are often unsatisfactory and of little value.
- Significant injurious and ineffective treatment occurs due to poorly calibrated ultrasound therapy machines.

Virtually all the western world countries hold satisfactory national physical standards for ultrasound therapy. There is also an abundance of equipment on the market to test ultrasound therapy machines. Regulation to ensure safe application of therapy ultrasound by regular calibration of the therapy machine ranges from nil to mandatory. Unfortunately, even where it is mandatory to test (USA), there is no effective scheme for ensuring that those who routinely test therapy machines are proficient in doing so.

What is missing is a cost effective traceability link from the clinical users through the routine testers to the national standards.

Corrective Action

It is clear that corrective action is overdue. The logistics of reaching each party involved in the use and testing of ultrasound therapy machines are forbidding. There are at least 14,000 therapy machines across Australia and about 100 individuals doing some routine testing. A routine tester may test anything from 10 machines/year (medium sized hospital) to 1,000 machines/year when servicing a large number of private practices and hospitals over a portion of a city. This type of test work is very seldom the sole source of income for a routine tester, neither is it particularly profitable. It is therefore unrealistic to expect a routine tester to report with his measuring equipment to a laboratory in order to assess his/her measuring proficiency and the calibration of his/her equipment.

One scheme to test the proficiency of the routine tester would be to dispatch to him/her a portable power standard (PPS). The PPS would resemble a commercial, clinical therapy machine but differ in several key aspects:

- It will be robust for travel through the usual commercial courier routes of air, rail and road.
- It will have a range of ultrasound transducers that bracket what is seen in clinical use. A negative control transducer would also be present.
- The output power will not be indicated on the front panel, rather a corresponding alphanumeric code. The code is to be quoted with the ultrasound power measured by the routine tester.
- The quality of the ultrasound will be more stable and of higher specification (eg beam uniformity, power) than what is available from commercial machines.

The proficiency assessment of the routine tester would occur by simply receiving the PPS, measuring its ultrasonic output as they would for a clinical machine (as a function of the front display codes), and then reporting their results with the display codes to the administering laboratory of the PPS. The administering laboratory would then assess whether the routine tester was performing an accurate measurement or if corrective tuition and/or equipment calibration were required.

The production of the PPS requires extensive experience in ultrasound measurement and the production of ultrasound fields. An European Union 5th Framework proposal is presently being put forward by NML and the national standards laboratories of the UK, the Netherlands and Germany. It is expected that NML will have a prototype PPS for trial use late in the year 2000.

The present IEC standards for therapy ultrasound machines [22, 26] are more suited for type, pattern and manufacturing QA testing. They are too unwieldy for clinical users and routine testers who require short, prescriptive documents for their particular situations. It is envisaged that the nature of these documents would be:

- Information articles in the professional journals and trade publications for clinical users and routine testers of medical equipment.
- Two standards in medical ultrasound:
  1. The clinical users' standard would prescribe simple daily checks for gross operational faults and how to obtain an annual calibration by a legally traceable routine tester.
  2. A standard giving detailed instructions to the routine tester on the minimum requirements for testing and reporting of the annual calibration of ultrasound therapy machines.

The work on the advisory standards has already begun in the Standards Australia technical committee HE/3/3 Medical Ultrasound.

The availability of a PPS together with the advisory publications and standards will provide a mechanism to enable the corrective action to be taken. The motivation for clinical users and routine testers to use the mechanism will be provided by ISO9000 quality assurance, medical insurance and voluntary accreditation through professional associations.

Spin-Offs

The effort in improving patient treatment with ultrasound therapy does have some useful spin-offs. The PPS as an exceptionally well defined source would enable considerably better dose estimation when conducting clinical research trials.

Australian manufacturers of ultrasound therapy machines will be able to draw on the expertise gained by NML staff. Some possible outcomes might include:

- an international review of what contributes to making an internationally competitive machine.
- advice on how quality control can be done most cost-effectively.
- the provision of compliance testing to Australian and overseas standards.

Lessons Learnt

In formulating and beginning this effort in therapy ultrasound, a number of lessons for a body like NML have been learnt:

Consultation: Extensive consultation is required with all levels of use of the technology, from the patients to regulators in other countries. This information gathering can be done effectively through the use of both formal and informal advisory groups. A good mechanism for the formal group is a Standards Australia technical committee. The informal group arises from identification of key players and stakeholders.

Effective Compliance: The correct questions need to be asked. Will the management scheme, advisory publications, standards and technical devices employed actually give a high degree of effective compliance at the end use of the technology? Does all the effort really make a difference to society and patient well-being?

A Driver: The gulf between NML and the patient is a wide one. The person required to bridge that gulf and ensure that useful work flows across it requires familiarity with all the levels of the problem.

4. OTHER AREAS

The breadth of ultrasound use can be seen in the range of Standards Australia committees that NML has interacted with:

- HE/3/3 Medical Ultrasonics.
- HE/3/-/5 Lithotripters.
- ME3 Sterilising Equipment
- MT7/3 NDT Acoustical Methods.
- TE6 Printed Circuit Boards.

Interestingly, interactions with such technical committees and introduction to other ultrasound technology areas often arises from users and manufacturers requesting NML assistance, sometimes anonymously. These anonymous alerts or "tip-offs" are, in the experience of overseas colleagues, often extremely valuable sources of information. A brief review of NML's interaction with the other uses of ultrasound of present interest will be given here.

Medical Ultrasonics

The use of ultrasound in medicine is very widespread. Millions of Australians every year will have some exposure to it.

Lithotripters generate ultrasonic shockwaves of more than 100 MPa with a duration greater than 100 ns. These multiple shockwaves are used to fragment hard deposits such as kidney and gall stones in humans. NML's interaction to the present has been restricted to the Standards Australia committee (HE/3/-/5) and maintaining an international watching brief on the standards of use of lithotripsy.

Diagnostic imaging ultrasound is extremely widely used (see the Introduction). It has been the area of highest growth in diagnostic imaging services funded by Medicare. NML interaction in this area has been restricted to providing information regarding the safety of diagnostic ultrasound to the Australian Health Technology Advisory Committee's (AHTAC) review of this technology. The peak power outputs of diagnostic imaging machines are often comparable to therapy ultrasound, but the duty cycles are extremely low, usually (2%. The dose and probability of adverse effects are accordingly extremely low. There has been some discussion in the Standards Australian committee (HE/3/3) regarding the introduction of some random compliance testing of diagnostic machines in Australia. The compliance test would be to FDA USA standards for these devices.

The use of ultrasound surgical units and dental descalers is very widespread. There have been comparatively few adverse problems with the clinical use of these devices. Accordingly, international standards activity in this area is low.

Power Ultrasonics

This area covers industrial applications where the total power is from 1 W to many kW. The most common application is the use of ultrasonic cleaning baths. These baths may be used in such diverse situations as cleaning surgical implements of human material (ME3 Sterilising Equipment), removal of solder flux from printed circuit boards (TE6 Printed Circuit Boards) and cleaning vegetables.

NML's involvement has been to resolve conflicts between stakeholders during the production of standards and to provide design and measurement advice for ultrasonic baths. However, due to the large power densities involved, conventional in-situ measurement methods are often of limited value and difficult to interpret. The number of queries in this application area is expected to rise slowly as industry explores the use of high power ultrasonics in the sonic processing of materials.

Underwater Acoustics

The term underwater acoustics is often used to describe waterborne military acoustics from the audible range to 500 kHz. The military use is usually confined to ranging, imaging and passive detection of other watercraft. Dr Suszanne Thwaites of NML is presently conducting a review of Australian military and civilian uses of underwater acoustics. This is in preparation for a forthcoming international comparison in underwater acoustics.

Non Destructive Testing/Evaluation (NDT/E)

This is probably the area where NML can make the most impact. However, to date, the medical area has consumed most of the NML effort. NML has provided informal advice and Quality Assurance testing of NDT/E transducers for a major Australian manufacturer of aerospace components for international clients. In addition NML is a member of the relevant Standards Australia committee (MT7/3) and interacts with the Australian Institute of Non-Destructive Testing (AINDT). A review of ultrasound NDT/E users in Australia and New Zealand by NML will shortly begin. The review will identify what is required in the way of measurement standards support and what measurement research assistance is desirable. In the long term it is expected that NDT/E will absorb most of NML's effort in ultrasound.

5. SUMMARY

Only a brief description of the effort in ultrasound by NML has been given. The present effort is directed towards therapy ultrasound but in the longer term NDT/E is expected to absorb most of the NML effort. Your comments would be most appreciated. [Adrian.Richards@tip.csiro.au]

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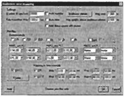

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ULTRASONIC GUIDED WAVES FOR INSPECTION OF BONDED PANELS

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ABSTRACT: This paper describes the propagation of "leaky" guided ultrasonic waves in layered planar structures, typical of adhesively bonded metal panels, when they are immersed in water. An outline of the physics of these waves is given, and the way in which they can be used to detect bond defects is indicated.

1. INTRODUCTION

Ultrasound is an important tool for characterising engineering materials, both for detecting discrete defects (cracks, voids, disbonds, inclusions, etc.) and for assessing material properties (e.g. elastic modulus, microstructure). It is widely used in industry, most commonly in the so-called pulse-echo configuration in which a single piezoelectric transducer, coupled to the surface of the material of interest, is used to excite a longitudinally-polarised pulse of ultrasound, and to detect signals subsequently back-scattered from structures within the material.

There are, however, a significant number of applications in which the material to be evaluated forms a structure in which at least one dimension is much smaller than another and which can, under appropriate circumstances, behave as a waveguide. Planar structures in which the thickness is much smaller than the lateral dimensions constitute an important class of such structures. Ultrasonic inspection of multi-layered planar structures is frequently required in, for example, the aerospace industry: examples are fuselage, wing and control surface skins, multi-layered carbon fibre composite laminates, adhesively bonded lap joints. In cases such as these it is often advantageous to make use of the guided modes that propagate in the structure, both from the point of view of the ability to excite specific dynamic stress distributions in the structure and/or to allow more rapid inspection of relatively large areas. Some examples of the use of ultrasonic Lamb waves, for which the particle motion in the wave is in a plane normal to the plate surface, have been described by Bowles and Scala [1]. A comprehensive review of guided waves in plates, and their use for materials evaluation, has been recently published by Chimenti [2].

This paper is concerned with leaky guided waves in planar structures. Whereas "true" guided waves are free vibrational modes of an elastic structure in vacuum, leaky waves are analogous modes that can be generated when the plate is immersed in a fluid, which may typically be air or water. These waves are excited by an incident wave from the fluid, and they decay by re-radiating (or "leaking") energy into the fluid on both sides of the plate. Mathematically, the difference is that the true guided waves are the solution of the vibrational eigenvalue problem for the plate, while the leaky waves correspond to the solution of the related scattering problem. If the fluid loading is light (i.e. the acoustic impedance of the fluid is much less than that of the plate) the leaky guided modes are very similar in structure and frequency to the true guided modes. This is normally the case for metals immersed in air or water, but it is not necessarily so for polymer-based materials in water.

The work described in this paper has been carried out over a number of years, as part of a collaboration between CSIRO and the Boeing Commercial Airplane Group. Most of it has not been published in the open literature. The physics of leaky guided waves is not new, though some aspects have not been previously reported. It is believed that the methods utilized here for presentation of the results provide useful insights into the way in which these waves propagate, and interact with an external wave field, and suggest novel methods for the development of defect detection strategies.

In the subsequent sections of this paper a brief introduction will be given to the leaky guided waves in an aluminium plate immersed in water, since water is often used as a coupling medium for ultrasound, particularly in laboratory studies. This will then be extended to consideration of an aluminium/epoxy/aluminium bonded structure, with a description of the way in which these waves are used to detect defective conditions in the bond-line.

The results described in this paper are derived from numerical calculations, but it is important to point out that all of them have been verified by experimental measurement. Some examples of experimental results are included. The overall aim of the program is to develop practical measurement techniques and procedures for characterisation of materials and structures, and for defect detection, and the parallel theoretical and experimental approach adopted is considered to be essential.

2. LEAKY GUIDED WAVES IN AN IMMERSED ALUMINIUM PLATE

Consider a flat sheet of aluminium immersed in water, as shown in Figure 1. An ultrasonic wave of frequency f is incident on the plate at angle θ, in the (x, z) plane of a

Cartesian coordinate system. It is assumed that the material properties are homogeneous and isotropic, so the elastic properties of the plate are isotropic in the (x, y) plane: the x-direction is determined by the incident plane.

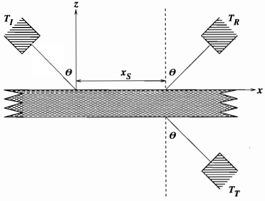

Figure 1. Schematic diagram of the experimental arrangement for generating and detecting leaky guided waves in a planar material. An incident ultrasonic wave is emitted by the transducer T_I, and waves reflected from and transmitted through the plate are detected by transducers T_R and T_T, respectively. The distance x_S is known as the transducer separation: if $x_S = 0$, direct reflection and transmission are measured.

The scattered wave field may be calculated by the following general procedure.

- Initially consider that the incident wave is an infinite plane wave in the fluid, incident at angle θ, with frequency f.
- Solve the wave equation in each of the bulk materials, for plane waves of frequency f. This gives longitudinal waves in the fluid half-spaces above and below the plate, and waves of both longitudinal and transverse polarization within the plate.
- Satisfy the boundary conditions at the fluid-solid interfaces as follows.
- The requirement of continuity at all times and positions on the interfaces leads to Snell's law, i.e. all waves that are present at an interface must have the same value for the wavevector component in the plane of the interface (all waves must have the same value of k_x). This implies that the wave fields can be generally expressed as a sum of partial waves, each of whose propagation angle is determined from the incident angle θ by Snell's law.
- Ensure continuity of normal displacement and stress across each interface, which leads to equations that determine the amplitudes and relative phases of each of the partial waves in each material layer, and which in turn define the wave field in the plate and the reflected and transmitted waves. Solution of the boundary condition equations results in expressions for the reflection coefficient R and transmission coefficient T of the form (see, for example, [3-6]):

$$R = \frac{X_a X_s - \tau^2}{(X_a + i\tau)(X_s - i\tau)}$$
$$T = \frac{i\tau(X_a + X_s)}{(X_a + i\tau)(X_s - i\tau)} \tag{1}$$

where X_a and X_s are functions whose zeros are the eigenvalues that define the symmetric and antisymmetric (with respect to the mid-plane of the plate) vibrational modes of the free plate, known as Lamb modes. Thus, the equations $X_a = 0$, $X_s = 0$ define the Lamb wave dispersion curves of the free plate. τ contains the effect of the fluid loading; it shifts the poles of the reflection (or transmission) coefficient off the real axis, thereby ensuring that the modes are leaky. A number of authors, including those to whom reference was made above, have studied the leaky guided waves in terms of the poles and zeros of the reflection coefficient. Equations (1) show how the reflection and transmission coefficients are related to the dispersion curves of the free plate.

- The finite extent of the incident beam can be taken into account by expressing it as an angular spectrum of plane waves (e.g [7]) and the reflected and transmitted beams determined by summing over the effects of all the plane waves in the angular spectrum. If it is assumed that the transducer behaves as a simple circular piston, the angular spectrum is simply the Fourier transform of the circular aperture function. The angular spectrum method for representing the diffraction effects resulting from a finite aperture is particularly convenient here because it makes use of the plane wave solutions of the problem obtained as above.

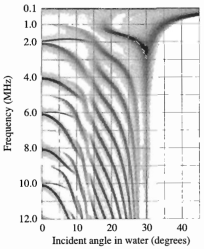

Figure 2. Calculated amplitude $R(\theta, f)$ of the wave directly reflected from the surface of a 1.60 mm thick aluminium plate immersed in water, as a function of the incident angle θ and frequency f. Black represents zero reflected signal, and white corresponds to total reflection. The transducers were 12mm diameter circular apertures.

The image in Figure 2 shows the amplitude of the reflection coefficient $R(\theta, f)$ for a 1.60mm thick aluminium plate immersed in water. These are calculated results, assuming 12mm diameter circular transducers that behave as ideal pistons, and taking the transducer separation to be zero (i.e. direct reflection geometry).

Experimental data, in the form of sets of measurements of $R(\theta)$ at various values of f, have been made and can be very well reproduced by these calculations. Data can be fitted by least-squares methods to determine the elastic and viscoelastic constants of the material, and their frequency dependence. An example of this will be given in the next section.

The results of Figure 2 illustrate some of the interesting physics of wave propagation in plates. The dark bands, where the reflected amplitude is small, are regions in which guided waves exist: most of the incident energy propagates down the plate and is re-radiated at larger values of x. These bands represent the dispersion curves of the guided waves, since the wavenumber of the guided waves is proportional to sin θ. If a similar calculation is done for $x_s > 0$, or of the transmission coefficient, the result is almost the inverse of Figure 2, since the guided waves now radiate energy rather than absorbing it. It can be seen from equations (1) that if the fluid loading is light (τ small) the dark bands almost coincide with the dispersion curves of the free plate: the modes are then known as leaky Lamb modes.

Images of the form of Figure 2 contain more information than just the location of the dispersion curves, however. The shades of grey indicate how well a mode is coupled to the incident wave in the water at that point in (θ, f) space, or how well it can be excited and detected. This is important if the modes are to be used for detecting defects in the plate. Some points of interest are listed below (see also, e.g., Auld [8], Pollard [9], Viktorov [10], or other texts on elastic waves in solids).

- The critical incident angle for longitudinal waves in aluminium, which is the incident angle for which the longitudinal wave is refracted parallel to the surface, is ~13.4°. For transverse waves it is ~28°. For $\theta < 13.4°$ the structure of the dispersion curves is quite complicated due to the coexistence within the plate of both longitudinal and transverse partial waves. For $13.4° < \theta < 28°$ the dispersion curves have a simpler structure due to the presence of only the transverse waves - the longitudinal partial waves are now evanescent.
- There are light vertical bands in the regions corresponding to the longitudinal and transverse critical angles at all except low frequencies. This is a result of the total reflection of plane waves that occurs at these critical angles. The effect is less clear at low frequencies because of diffraction effects. The fixed aperture transducers generate more divergent beams at low frequencies, so, when the transducer is directed at the critical angle, only a relatively small proportion of the beam energy is incident at this angle.
- All of the modes except two converge to the transverse critical angle ($\theta \sim 28°$) at sufficiently high frequencies. Thus the high frequency limit of the phase velocity of all of these leaky Lamb modes is the bulk transverse wave velocity.
- The two modes at low frequency that do not converge at the transverse critical angle at high frequencies are the zeroth-order symmetric and antisymmetric Lamb modes, often referred to as S_0 and A_0, respectively. The phase velocity of the antisymmetric mode A_0 tends to zero at zero frequency, so the angle at which it is excited becomes large at low frequencies. This mode is the simple bending mode of the plate. The symmetric mode S_0, on the other hand, tends to a finite phase velocity, close to the bulk longitudinal wave velocity, at low frequencies: it resembles a longitudinal wave propagating down the plate.
- The two zeroth-order Lamb modes coalesce at about 2.5MHz to form Rayleigh waves, which are confined to the surfaces of the plate. The Rayleigh waves, which are dispersionless, are excited at $\theta \sim 30°$ and penetrate into the plate to a depth of the order of the wavelength. The zeroth-order Lamb modes may be thought of as the symmetric and antisymmetric couplings of a Rayleigh wave propagating on each surface of the plate. At high frequency they are effectively independent of each other, but as the frequency is decreased they penetrate further into the plate and their coupling increases, producing a splitting at $f \sim 2.5$MHz.
- At high frequencies, only the Rayleigh wave on the incident surface is excited. For infinite plane wave excitation, this wave will absorb no nett energy from the incident beam: all of the energy that goes into the Rayleigh wave will be re-radiated and will appear as reflected energy, albeit with a phase shift to account for the re-radiation delay. For the finite beam case shown in Figure 2, the fixed aperture transducer approaches a plane wave source at high frequencies, so the amount of energy removed from the beam by the Rayleigh wave decreases as the frequency is increased.

To show how information such as that in Figure 2 can be used, attention is now turned to the case of a multi-layered plate—an adhesive bond.

3. LEAKY GUIDED WAVES IN AN ADHESIVELY-BONDED ALUMINIUM PLATE

Consider now a structure that consists of two aluminium sheets bonded together by a thin epoxy adhesive layer. The waves propagating in such a three-layered structure can be calculated using the same general procedure outlined in the previous section, but in this case there are four partial waves in each solid layer. The wavenumbers and propagation directions of these partial waves are determined by the elastic constants of the layer material and Snell's law—the x-components of the wavenumbers of all partial waves in all layers are equal. The (complex) amplitudes of the partial waves are determined by the boundary conditions, bearing in mind that in this case there are additional boundary conditions that must be satisfied at the two solid-solid interfaces within the plate. For a well-bonded interface there are four such conditions: continuity of normal and tangential particle displacement (or velocity) and of normal and shear stress across the interface.

Figure 3 shows the amplitude of the reflection coefficient $R(\theta,f)$ for a water-immersed bonded plate typical of structures encountered in airframes. These results are directly comparable with those for the aluminium sheet shown in Figure 2. Figure 4 shows the results of experimental measurements of the reflected amplitude from a bonded plate similar to that for which the calculations of Figure 3 were performed. These results give confidence that the computational model is a reasonable one.

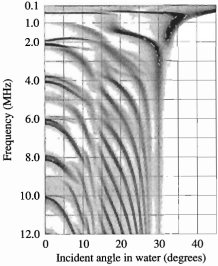

Figure 3. Calculated amplitude $R(\theta,f)$ of the wave directly reflected from the surface of an adhesively-bonded aluminium plate immersed in water, as a function of the incident angle θ and frequency f. Black represents zero reflected signal, and white corresponds to total reflection. The plate consists of two sheets of 1.60mm thick aluminium, well-bonded by a 0.25mm thick layer of epoxy adhesive. The transducers were 12mm diameter circular apertures.

It is apparent that, over much of the (θ,f) space shown in Figures 2 and 3, the general pattern of the dispersion curves is very similar for the single aluminium sheet and the bonded plate. The reason for this is that in much of the region the bonded plate behaves like two identical resonators (the Al sheets) coupled by a relatively soft spring (the adhesive layer). There are, however, regions where the structure of the dispersion curves for the two cases differ significantly. These regions are of great interest, because it is expected that here the modes will be most sensitive to the properties of the bonding layer.

In particular, attention is drawn to the following regions of difference.

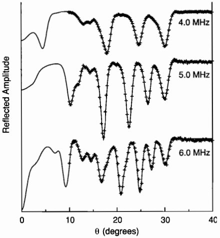

Figure 4. Measured amplitude of waves directly reflected from the surface of an adhesively-bonded aluminium plate immersed in water, as a function of the incident angle θ, at the frequencies indicated. The crosses are the results of measurements made using long (~100 μs) tone-burst pulses to approximate continuous waves. The solid lines are the results of a least squares fit, to all three sets of data simultaneously, using the model described in the text. The plate consisted of two sheets of 1.60mm thick 2024 aluminium, well-bonded by a 0.24mm thick layer of epoxy adhesive (FM-73, American Cyanamid). Two 12mm diameter, 5MHz centre frequency transducers were used.

- The existence of a mode in the bonded plate at ~0.5MHz, over a wide range of θ, for which no equivalent exists for the single aluminium sheet. At normal incidence this is a (symmetric) thickness resonance of the bonded plate, with most of the strain in the adhesive layer because of its relative softness. It is a symmetric mode that is derived from the zero-order antisymmetric Lamb mode of the single sheet: the motion in each of the Al sheets is antisymmetric while that in the adhesive layer is symmetric. Because the motion in the adhesive layer is symmetric, the stress in this layer is mainly normal to the plate surface. The shear stress introduced at higher incident angles is confined mainly to the Al sheets.
- Sharp, narrow modes occur in the single aluminium sheet at and near normal incidence ($\theta = 0$) at 2,6,10, . . . MHz, which are not present in the bonded plate. These are thickness-shear resonances in the aluminium, and they are strongly damped by the presence of a bonded adhesive layer on the aluminium surface. These modes and their excitation have been described in more detail previously [11], and they will be encountered again below. They are generated by mode conversion of components of the incident beam that are not exactly normal to the surface, and they are "pumped" by the adjacent symmetric longitudinal resonance in each case.

- A broad, weak minimum that occurs for the bonded plate at small incident angles near $f = 4.8$MHz. This is the thickness resonance of the adhesive layer.
- A number of transverse modes of the bonded plate, particularly in the region around $\theta \sim 20°$, $f \sim 3$MHz, are associated with the adhesive layer.

4. DETECTION OF DEFECTS IN A BONDED PLATE

The use of leaky guided waves for detecting defects in planar bonded structures requires a means of determining which modes are sensitive to particular defects. This can be done qualitatively by consideration of the stress and strain distributions generated by a particular mode, and the way in which the ideal and defective materials would respond to these distributions[12,13]. The computational model described above can be used to calculate stress and strain distributions associated with particular modes for use in such analyses. To take a simple example, a closed disbond, coplanar with the plate surface, would be not be detectable in a compressive normal stress, though it might be if the stress was tensile and sufficiently large. However, a shear stress applied across such a defect would be expected to produce a significantly different response from that in the absence of the disbond.

Images of 2D data sets such as those shown in Figures 2 and 3 suggest a simple empirical method for the identification of modes that are sensitive to planar defects. The defect is assumed to be infinite in lateral extent. It is included in the numerical model and an image of the reflection or transmission coefficient of the defective structure obtained. The difference between this image and a comparable one for the ideal structure can then be found by subtraction of the images, and regions of the (θ, f) parameter space where there are significant differences can be immediately identified. Even if the real defect is not large, the modes that are perturbed by the infinite model of the defect will be scattered by one of finite extent. Two examples of this procedure and its results will be very briefly described.

4.1 Detection of a closed disbond

The first example is that of a closed disbond, a situation that occurs when there is delamination of the adhesive from the metal, perhaps as a result of poor surface preparation, surface contamination or in-service water ingress and interfacial corrosion. The bond is held tightly closed, perhaps by structural stresses, but it has no shear strength. This is a defect that cannot normally be detected by traditional through-transmission or pulse-echo ultrasonic inspection techniques. It is incorporated into the computational model by relaxing the condition that the tangential displacement and shear stress be continuous across the metal/adhesive interface.

The results are shown in Figure 5, which corresponds to the case of a disbond at the upper (referred to the orientation shown in Figure 1) aluminium/adhesive interface. Similar results are found for a disbond at the lower interface. The difference image shows that the most significant differences are near normal incidence at $f \sim 2$, 6, 10MHz (in fact, the resolution of the images of Figure 5 is not sufficient to show the strong but very narrow modes that occur at and close to normal incidence at 6 and 10MHz). Further investigation shows that, in the presence of the disbond, the symmetric thickness-shear resonances of the single aluminium plate, referred to above, have reappeared in the disbonded sheet.

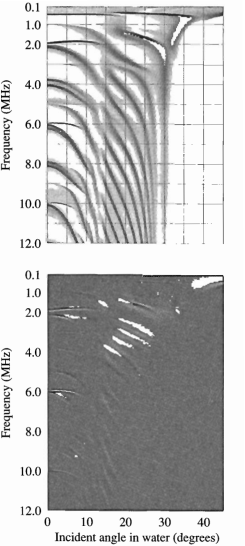

Figure 5. Calculated amplitude $R(\theta, f)$ of the wave directly reflected from the surface of an immersed, adhesively-bonded aluminium plate with a closed disbond at the upper aluminium/adhesive interface, as a function of incident angle θ and frequency f. The upper image is comparable to Figure 3 while the lower one is the difference between the images for the disbonded plate (upper) and the well-bonded plate (Figure 3).

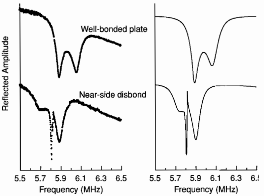

Figure 6. Reflected spectra for two different plates, as described in the text, for normal incidence ($\theta = 0$). Spectra measured using a 12mm diameter, 5MHz centre frequency transducer are on the left, with calculated spectra on the right. The sloping baselines of the measured spectra are due to the frequency response of the transducer, which is not included in the calculations.

This is also true if the lower sheet is disbonded.

These results have been verified experimentally, a typical example being shown in Figure 6. In this case the closed disbond was simulated by fabricating a bonded plate with a release agent in one of the aluminium/epoxy interfaces, so that it was readily delaminated after curing. In order to exclude air from the disbond, the two parts of this plate were clamped together under water, trapping a thin water film in the delaminated interface. The sharp feature at approximately 5.8MHz in Figure 6 is a result of the aluminium thickness-shear resonance referred to above. Although it is difficult to see in this figure, the measured data in this region show that this mode is broadened by the small rolling-induced anisotropy of the aluminium sheet. A practical technique based on the detection of these modes has been developed [11].

4.2 Detection of reduced elastic modulus of the adhesive

The second example is of detection of a degraded material property rather than of a discrete defect. Reduced elastic moduli of the adhesive may result from, for example, inadequate curing of the adhesive, incorrect adhesive composition, microcracking within the adhesive, etc. This condition in incorporated into the model by simply reducing the values of the elastic constants of the adhesive layer, and the results are given in the form of the difference image in Figure 7.

It can be seen that most of the modes near normal incidence show sensitivity to this condition, since they are essentially thickness resonances of the plate. However, this is not very useful in practice since there is considerable ambiguity with bond thickness: the observed sensitivity is almost completely removed if the adhesive layer thickness is reduced in the same proportion as the elastic constants. Since, in practice, the exact thickness of the bond is generally not known, the thickness resonances cannot be used to measure the adhesive properties.

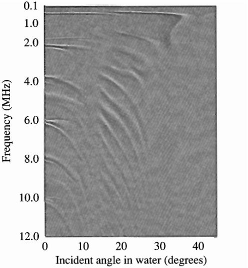

Figure 7. Calculated amplitude $R(\theta, f)$ of the wave directly reflected from the surface of an immersed, adhesively-bonded aluminium plate with the elastic moduli of the adhesive reduced by 10% from the values used to calculate the data in Figure 3, as a function of the incident angle θ and frequency f. The image shown is of the difference between the data for the reduced modulus plate and that for the well-bonded plate (Figure 3).

There is less ambiguity and substantial sensitivity, however, in the 0.5MHz symmetric mode derived from the A_0 modes of the aluminium sheets, described in Section 3. The frequency of this mode depends on the adhesive layer thickness, but not in the same ratio, so this mode, possibly in combination with measurements of thickness resonances, may be used to measure adhesive modulus.

5. CONCLUSIONS

A brief introduction has been given to some features of the propagation of leaky guided waves in multi-layered planar structures immersed in a fluid, and the utility of these waves for characterisation of structures such as adhesively bonded joints has been illustrated. While the emphasis in this paper has been on computational results, a parallel experimental program has been carried out and the results presented here have all been verified by measurement. The approach has been to use the generality and flexibility of water immersion techniques to determine how a particular defect, or class of defects, may be detected, and to use this information to design a specific practical inspection technique.

The calculations outlined here are part analytical and part numerical. Solutions of the wave equations for the various materials, and Snell's law of spatial continuity, are used to determine the nature and orientation of the partial waves that are used as basis functions for numerical solution of the boundary condition equations. This approach has the advantage over a fully numerical method, such as a finite element calculation, of providing greater insight into the physics of the wave propagation. The advantage over a fully analytical solution, which is possible for the single layer plate (see equations (1)) is that it can be readily extended to the case of multi-layered plates.

This method can also be extended to describe wave propagation in multi-layered anisotropic materials, such as carbon fibre composite laminates [2]. Work on these materials has been done within this laboratory, to find methods to detect inclusions of foreign materials embedded in composite laminates [14,15]. Material anisotropy adds considerable complexity to both the model and the results, but the general principles are the same as those presented here for isotropic materials.

Current theoretical and experimental work in this program is aimed at extending the approach outlined here to describe the non-linear propagation of large amplitude leaky guided waves, in the limit of weak non-linearity. It is known that some classes of material conditions, such as fatigue microcracking, and some microstructural properties such as hardness, have a much greater effect on the non-linear response of materials than on linear wave propagation. There are also indications, not yet unambiguously confirmed, that some mechanisms that lead to weak adhesion of bonded joints and surface coatings may lead to enhanced material non-linearity. The program of non-linear guided wave propagation in layered structures is aimed at investigating these problems. The non-destructive detection of weak adhesion is currently not possible.

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Book Reviews...

Computer Speech Recognition, Compression, Synthesis

M R Schroeder

Springer Verlag Publishers, 1999, pp 313, Hard cover, ISBN 3 540 64397 4, Australian Distributor: DA Information Services, 648 Whitehorse Road, Mitcham, 3132, Australia, tel 03 9210 7777, fax 03 9210 7788. Price A$76.25

The book under review covers a wide range of topics, which are indeed fundamental to the multi-disciplinary area of speech science and technology. There are ten core chapters, which are preceded by a four-page preface of primarily personal recollections and a twelve-page chapter of acknowledgments. The book also contains two appendices (A and B), which are followed by a glossary of relevant terminology acquired to date, a comprehensive bibliography with a name and a subject index, and finally a one-page biographical description of the author.

Chapter 1 (Introduction: 21 pages) introduces the reader to human and computer speech communication by providing an overview of the complexities, challenges and benefits associated with endeavours in the area of speech science and technology. Chapter 2 (A Brief History of Speech: 18 pages) is a further introduction that provides a helpful perspective on cornerstones of computer analysis, synthesis and recognition of speech. The historical highlights offered in these introductory chapters represent a valuable contribution towards achieving the purported aim of informing the "non-specialist".

Chapters 3 (Speech Recognition and Speaker Identification: 17 pages), 4 (Speech Compression: 20 pages), 5 (Speech Synthesis: 5 pages), 6 (Speech Production: 12 pages) and 7 (The Speech Signal: 3 pages) are primarily of a tutorial, qualitative nature with a continuing historical undertone. While these chapters are by themselves informative, the reader should be warned that the author makes little effort to secure inter-chapter transition or to foreshadow the unconventional order of presentation. The reader should also be advised that Chapters 5 and 7 are far too brief, which is the author's choice and not necessarily an accepted fact that the topics treated therein are not or no longer important.

Chapters 8 (Hearing: 25 pages) and 9 (Binaural Hearing: 27 pages) account for a large part of the book. Quite clearly, the author exhibits competent knowledge of the hearing mechanism and the perceptual processes in humans with again useful historical accounts. Last but not least, the machinery in place for analysing speech signals in the time and the spectral domain is described in the final Chapter 10 (Basic Signal Concepts: 38 pages).

Appendix A gives a comprehensive treatment of the physical properties of the human vocal tract, together with useful notes on the many-to-one problem of inferring vocal-tract shapes from acoustic parameters. The reader should be cautioned that Appendix A is written by a different author - a fact that is mentioned quite late on page 101 of the book. Appendix B consists primarily of a mathematical derivation of direct relations between two powerful parameters of speech - the linear-prediction predictor and cepstrum coefficients.

In sum, I am inclined to recommend Schroeder's book as an auxiliary reference in an area, which is still relatively new and thus in need of a range of views and treatments of the subject matter. Perhaps the most serious weakness of the book is its preface, which provides very little guidance to the technical contents, and therefore does not prepare the non-specialist or the specialist for the adopted sequence of and the weights given to a wide range of inter-connected topics. By contrast, the historical accounts provided by the author are a noteworthy contribution, which meshes well with Pliny's reflection that "not to know what has happened before you is to be a child all your life".

Frantz Clermont

Frantz Clermont lectures on numerical analysis and computer speech processing at the School of Computer Science of the University College of the University of New South Wales, Australian Defence Force Academy. He was the recipient of the 1997 University College award for teaching excellence.

Acoustics Applied to Music: The evolution of ideas and methods

H Pollard

Selfpublished, 1999, pp 218, soft cover, ISBN 0 646 38065 6. H Pollard, 6 Wren Place, Cronulla, NSW 2230, Australia, tel 02 9523 4655, fax 02 9717 9268. Price A$24.50 (incl. postage in Aust A$29.85, overseas $35.50)

There are no equations in this book. Zero— I've counted. Sabine's work and the decibel are discussed without them. To readers of Acoustics Australia this may seem stranger than a lipogram but let's be honest: we are in the minority. There is a huge reading public who, seeing equations in a book, will put it back on the shelf. And among that large, numerophobic public there are some people (especially musicians) take their music very seriously. You've met them at parties: they find out you do acoustics and pin you down with questions about live vs dead spaces, about presence and frequency response. And that leads on to hearing and hi-fi and temperament.

But by now you've run out of space on the napkin and you need another drink. You'd think about recommending Rossing but you have a numerophobe in front of you. You're saved: Howard Pollard has written this book for your interlocutor -- and it's cheap!

Many topics are covered: Room acoustics, the development of musical science, the points of view of the scientist and the musician, the nature of sound and its radiation, measurement techniques, spectra, recording technologies, the physiology of hearing, auditory psychophysics, temperaments and the theory of consonance. This great breadth means that the treatment is relatively brief, but that is entirely consistent with the book's aim of addressing the lay reader.

The chapters are interspersed with short profiles of such important figures as Pythagoras, Mersenne, Newton, Edison, and many others. Many of the chapters are followed by short 'extensions' for those who wish to know more about details which have been glossed over in the main text. It has many figures: mainly diagrams but there are some photographs. There's a list of references at the end of each chapter, a topic index and an index of technical terms. (When each technical term is introduced, there is a foot note explaining what it is.) For the purposes of the book, the bibliography is adequate. The sections on physiology and perception and that on acoustically modelling do not include the considerable progress of the last decade, but this would in any case increase the complexity considerably and defeat the book's purpose.

The figures look a bit 'old-fashioned'. This is not intended as a criticism: for instance, the line drawings that explain longitudinal travelling waves and standing waves (5-6 and 5-7) show density, displacement and velocity as functions of time and position in a very effective way. The quality is uneven, however: the charts that begin many of the chapters and which show how the topics are related (an excellent idea) are laid out in an awkward and unattractive way. The net result is that the book may appear less attractive to a reader used to modern introductory text books with expensive graphics and high quality layout.

But a book with colour pictures, elegant layout and a lot of extra blank areas on the page would cost much more than $25.

The book is a remarkable achievement. It really does give a good explanation of the wide range of topics in a way that is readily understandable to a non-scientific but interested reader. It's an enjoyable read for a specialist, too. And you could always buy one to have on hand for the next time someone finds out you work in acoustics and starts posing those questions.

Joe Wolfe

Joe Wolfe researches the acoustics of musical instruments and the voice at the University of New South Wales. (www.phys.unsw.edu.au/music).

Noise in the Workplace Training Course

WorkCover NSW

WorkCover NSW,
128 Marsden St, Parramatta 2150,
tel 02 9841 8512, fax 029841 8567.
Price includes accreditation A$750.

The WorkCover NSW Noise in the Workplace training package has obviously been carefully designed to meet the needs of workplace training. It is well presented in a large ring binder which will allow updates when necessary.

The package comprises written material, a copy of an excellent video which was produced by Worksafe Australia and a tape recording of various noises. It could provide a very useful resource for all those involved with training in occupational noise management.

The written material contains notes for the trainer which includes the learning outcomes and assessment criteria for each session as well as the time allocation. The presentation of the Employee's course takes four hours and the Supervisor's six and a half hours. The presentation of the course is structured and the various actions are identified. For example these include asking the participants questions, playing specific sections of the audio tape and video, discussing or explaining points, provision of handouts, use of overheads, points to emphasis and summaries of each session etc. Eight overhead slides and ten handouts are provided. The handouts must be copied by the presenter for each of the participants attending training.

In addition there is a 48 page information manual and copies of relevant WorkCover NSW documents to provide background information for the presenter. The information manual essentially provides, in a concise form, all the reference material required by the presenter of the course.

Although accreditation is not legally required to present Occupational Health & Safety training in NSW, WorkCover NSW is dedicated to assisting organisations and individuals in improving their training strategies for occupational health and safety. Therefore, a system of trainer accreditation has been introduced to encourage industry trainers, those who have direct industry knowledge and experience, to deliver training using WorkCover NSW approved packages. The WorkCover NSW Noise in the Workplace training package is only available to trainers who successfully complete the WorkCover NSW OHS accreditation process.

The accreditation process requires submission of a detailed application, provision of supportive evidence and payment of $750. The training package is provided at the successful completion of the Orientation Program. The course itself has received accreditation under the NSW Vocational Education and Training Accreditation Board.

Marion Burgess

Marion Burgess is a Research Officer with the Acoustics and Vibration Unit at the Australian Defence Force Academy in Canberra.

The Boundary Element Method in Acoustics

Stephen Kirkup

Integrated Sound Software, 1998, pp148+CD, Soft cover, ISBN 0 9534031 0 6, Available from www.soundsoft.demon.co.uk/ or 25 Smithwell Lane, Heptonstall, Hebden Bridge, West Yorkshire, HX7 7NX, England. Price for core package of book and disk for all the 2D problems UK£52.50 or development package of book and CDROM for all the 2D, 3D and axisymmetric codes UK£230.

With the advent of cheaper and more powerful computers and the desire to optimise design, there is a fast growing trend of using numerical tools to solve acoustic problems. Recently, the boundary element method (BEM) has gained more and more exposure over the finite element method in the numerical acoustics community, especially in predicting exterior radiation problems. The increasing number of commercially available software using BEM is a good indication of its acceptance. There are already numerous books that treat the boundary element method for solving acoustics problems. This book is different from most other books on the subject in that it is more like a manual on how to implement the boundary element method. A library of Fortran 77 subroutines is provided in a CD that accompanies the text and the users are assumed to have a working knowledge of Fortran.

The book consists of six chapters. An outline of the boundary element method and the Helmholtz equation is given in Chapter 1. Although detailed derivation of the mathematical equations is not provided, the basic equations are introduced. Both the direct and indirect integral equations are given. The advantages of the boundary element method over the finite element method are highlighted. Chapter 2 shows how a boundary (line or surface) can be discretised into panels. The techniques used to reduce the integral equations to discrete form are considered in Chapter 3. The regular integrals are evaluated using Gauss-Legendre quadrature rules and special numerical integration methods are given for evaluating the non-regular integrals. Fortran 77 numerical integration subroutines are provided for two-dimensional, three-dimensional and axisymmetric three-dimensional problems. A commendable feature is the analysis of the computational cost involved in evaluating the integral operators.

The solution of three classes of acoustic problem is discussed in detail in the remaining three chapters of the book: the interior acoustic problem, the exterior acoustic problem, and the interior modal analysis problem. Although both the direct and indirect boundary element methods are described, only the direct method is implemented in the Fortran subroutines provided. Test cases for two-dimensional, three-dimensional and axisymmetric three-dimensional problems are given in each of Chapters 4, 5 and 6 to validate the methodology as well as the Fortran programs.

The structure of each of Chapters 4, 5 and 6 is very similar. Firstly the direct and indirect integral formulations are introduced, followed by the implementation using the boundary element method for two-dimensional, three-dimensional and axisymmetric three-dimensional problems. A 'practical' application example is given at the end of each Chapter: the interior acoustics of a 2D car in Chapter 4, the engine noise analysis in Chapter 5 and the analysis of a loudspeaker enclosure in Chapter 6. In addition, in Chapter 5, the scattering problem is considered and the difficulties in applying the boundary element method to exterior problems are discussed. The popular

Schenck method (also known as the CHIEF method) for extending the solution to higher wavenumbers in exterior problems has been described but is not provided in the Fortran subroutines. Instead, the author implements formulations in the Fortran subroutines that he believes to be better than the Schenck method.

The emphasis of most modern commercially available software is on the ease of use normally through a graphical user interface (GUI) and powerful pre- and post-processors. Sometimes, these fancy graphical tools have detracted the users from being aware of the limitations and accuracies of the BEM solvers. In contrast, this book is concentrated only on implementing the BEM solvers. The author has adopted a systematic approach in introducing the boundary element method and the book is easy to read with very few typographical mistakes. For those (postgraduate students, researchers and practicing acousticians included) who would like to learn about the actual mechanics of how the boundary element method works and write their own computer codes, this book is a useful and practical guide. Even those who use commercial BEM software will benefit from an improved understanding of the intricacies involved in the 'black' box supplied in their software.

Joseph Lai

Joseph Lai is the Director of the Acoustics and Vibration Unit at the University College at the Australian Defence Force Academy. He has considerable experience with the use numerical tools for acoustics and vibration problems.

Psychoacoustics: Facts and Models

E Zwicker and H Fastl

2nd Edition, Springer Verlag Publishers, 1999, pp 416, soft cover, ISBN 3 540 65063 6, Australian Distributor: DA Information Services, 648 Whitehorse Road, Mitcham, 3132, Australia, tel 03 9210 7777, fax 03 9210 7788. Price A$80.75

People working in the field of acoustics are accustomed to making physical measurements of quantities such as frequency, sound pressure level, and distortion level, and these measurements can now be made with a great deal of precision and reproducibility. What we sometimes tend to forget is that pressure oscillations do not properly become "sound" until they have been heard by some animal, and of course our attention focuses upon hearing by humans. How is what we hear related to the physical quantities that can be measured by sound level meters and spectrum analysers? Finding answers to this question provides the subject matter of the field called psychoacoustics.

The study of human hearing was begun by Herman von Helmholtz (1821-1894) and greatly expanded by Georg von Békésy (1899-1972), though both were perhaps more concerned with physiology than with psychology. More recently, psychology has come to the fore in the study of hearing, as in many other areas, and nowhere more than in Germany. The group that flourished from 1952 to 1967 in the Institute of Telecommunications in Stuttgart, and then since 1967 in the Institute of Electroacoustics in Munich, has made notable contributions to the subject, and it is with these that the present volume, first published in 1990, is concerned. Professor Zwicker, the first author, died shortly after publication of the first edition, but his co-author, Professor Fastl has ably undertaken the task of up-dating the treatment without fundamentally changing the approach or content.

This is an unusual book, because its explicit aim, as set out in the preface to the first edition, is to make the work of these two German groups more widely available to the English-speaking world. This might seem to make the work rather parochial, and indeed references are limited to the work of these two groups, but their interests have been so nearly universal that the total presentation is broad and covers most parts of the subject in considerable detail. In contrast with other books, there is very little physiology in the book, and the measuring instrument used is the response of groups of human subjects.

Most of the expected topics are treated in detail, with major emphasis being given to masking, pitch and loudness. Critical band rates (measured in Barks, for those who don't know) are central to the discussion, and we meet other well-known psychophysical units such as phons (for loudness) and mels (for pitch), as well as some quite new to me, such as the acum for measuring sharpness and the asper for measuring roughness. I confess that the discussion of these quantities failed to make them entirely clear to me! There is a rather short final chapter on applications, which discusses noise abatement and audiology, with brief mention of other topics such as speech recognition, musical acoustics and room acoustics.

The book is a goldmine of experimental data covering virtually the whole field of psychoacoustics, and the explanations given are generally clear and concise. For those who want to follow up the original papers published by the group, the bibliography is excellently organised into topics, and the titles of the German language papers (which account for rather more than half of the total) are translated into English.

I found reading the book an instructive occupation. It is perhaps a little too detailed for the casual reader, but for those carrying out experiments or interpreting results in terms of what people actually hear, it is excellent. While serious workers in the field will doubtless complement this treatment with something covering particularly work from the United States, this book succeeds admirably in its avowed purpose of summarising the German work and presenting a clear overview of the subject.

Neville Fletcher

Neville Fletcher is a Visiting Fellow in the Research School of Physical Sciences and Engineering at the Australian National University..

Acoustic Consultant

RFA Acoustic Design Pty Ltd seeks application from persons with qualification and experience in acoustic design appropriate to a senior consultant position. The position, as a design manager, includes responsibility for assigned project commission planning and management, supervision of commission support staff where required, and an involvement in the professional practice management of the company.

RFA is an eminent consultant with major project credits throughout Australia and Asia, including Star City Casino, Lyric Theatre, Fox Studios Australia, Kuala Lumpur Airport Terminal, Sydney and Brisbane international terminals, Ansett Sydney, Darling Park, Renzo Piano Building, and many others. The company promotes an active staff participation in company planning and development and we are seeking a person who can also sustain a high level of communication with our clients. RFA operates under an accredited ISO9001 quality assurance system which seeks a high level of professional commitment to our industry and client base.

In the first instance, please express interest by telephone to Robert Fitzell on (02) 99 100 400 after which confidential application in writing and interview by invitation would follow.

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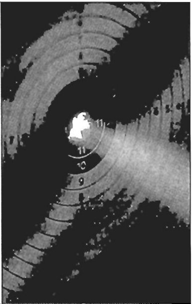

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Brüel & Kjær

News...

2000 AAS CONFERENCE

ACOUSTICS 2000, the AAS Conference marking the turn of the century, will be held in Perth on 15-17 November, 2000. This will be a time to consider how well the acoustics profession is serving the community in applying the best available science and technology.

The emphasis of the Conference will be on practical applications of acoustical science and technology and practical solutions to acoustic problems.

Topics will include:

- architectural acoustics
- environmental noise
- occupational noise
- engineering noise control
- speech and hearing

The Conference will commence on Wednesday evening, 15 November, with registration and an informal social function. Two parallel papers sessions will run on Thursday 16 November. The Conference Dinner will be held on the Thursday evening. A further papers session and Workshop will be held on the Friday, and there will be trade displays both days.

Enquiries:

The Conference Secretary
Australian Acoustical Society, WA Div
PO Box 1090, West Perth, WA 6872
or by e-mail to:
Tien Saw: barclays@iinet.net.au
DanielLloyd: dlloyd@ermperth.erm.com.au

INTER-NOISE 2000

The 29th International Congress on Noise Control Engineering to be sponsored by I-INCE, the International Institute Noise Control Engineering, will be held in Nice on the French Riviere from August 28-30, 2000. The theme of Internoise 2000 will be closely related to transport and community noise but all subjects in noise and vibration engineering will be discussed including noise sources: emission and control, measurement techniques and analysis, modelling and prediction, environmental noise, effects of noise, sound quality, transport noise control, building noise control, noise policy, standards and regulations. A technical exhibition will be held during the conference and there will be a full social program. The deadlines for Internoise 2000 are; receipt of abstracts 15 January 2000, acceptance notification 29 February 2000 and Manuscripts by 30 April 2000.

More information from: http://internoise2000.loa.espci.fr/ or the congress secretariat SFA, 23 avenue Brunetière, 75017 Paris, France; Fax: +33 1 4788 9060;

Two joint events to be held around the time of Internoise 2000 are:

• NOVEM Noise & Vibration: Pre-design and characterisation using energy methods. NOVEM is a follow-up of 4 international congresses on acoustic intensity. It will cover energy methods which show industrial potential and applicability. The aim is to expose the current level and explore the future evolution of these methods when used for either early design or characterisation of noise and vibration. It will be held at the new Lyon Congress Centre from 31 August - 2 September 2000, Lyon, France.

Details: Goran Pavic, novem@lva.insa-lyon.fr fax: +33 4 7243 8712
http://lva.insa-lyon.fr/novem2000/

• 5CFA: Fifth French Congress on Acoustics This will be organised by the French Acoustical Society in association with the Swiss Acoustical Society and will be held at l'Ecole Polytechnique Fédérale in Lausanne from 3-6 September 2000.

Details: CFA 2000, Laboratoire
d'Acoustique (UMR CNRS 6613) Institut
d'Acoustique et de Mécanique (IAM) ,
Université du Maine 72085 Le Mans Cedex
9 - France cfa2000@univ-lemans.fr
http://cfa2000.univ-lemans.fr

ICSV7

The 7th International Congress on Sound and Vibration (ICSV7) will be held July 4 - 7, 2000, in the modern Convention Center of Garmisch-Partenkirchen, the famous mountain resort in the Bavarian Alps, Germany, about one hour south of Munich. The congress is sponsored by the International Institute of Acoustics and Vibration, IIAV and follows congresses in Australia (1997) and Denmark (1999).

Around 500 abstracts of papers have been submitted for presentation and more are coming in.

Special late abstract acceptance date of January 31 for Australia, by email only to address below.

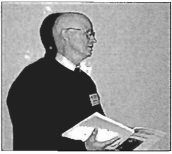
Further information is available from http://www.bs.dlr.de/icsv7/ and the Congress Secretariat ICSV7, Congress & Seminar Management, Industriestrasse 35, D-82194 Groebenzell, Germany. Fax: +49 8142 54735 info@csm-congress.de

AUSTRALIAN ACOUSTICAL SOCIETY 1999 CONFERENCE "ACOUSTICS TODAY"

The theme of the conference was that acoustics of today has grown from the knowledge and skills of the past. The Conference was dedicated to the memory of H. Vivian Taylor, the first President of the Society and a very well respected acoustic consultant in both Victoria and New South Wales. Each day's proceedings started with an invited paper about the Society's past and changes that have occurred over the intervening years. These papers were presented by Gerald Riley and Anita Lawrence, both foundation members of the Society. A highlight of the Conference was a very interesting display of acoustic memorabilia, including thermionic valve operated equipment that H Vivian Taylor once used.

A very interesting series of papers were presented and a workshop held where old equipment was demonstrated. Much to the delight of the audience, a number of amusing stories of the past were told during the workshop. The prize for the oldest item was awarded to Fergus Fricke for a strange looking brass device that was one of a set of Helmholtz resonators made in London in 1882. This curious object is placed in a person's ear and resonates at a set frequency. The prize for the most interesting piece of equipment was awarded to John Davy for a demonstration of the mysteries of a set of 1950s Bruel & Kjaer equipment.

The Conference Dinner consisted of an exciting night train ride on Puffing Billy and dinner at the Nobelius Packing Shed at Emerald. For many, the Annual General Meeting of the Society held after the first course may have been a necessary, but boring, interlude. However, the subsequent talk by Hugh Vivian Taylor about his father had members spellbound. His father's original diary shows that he started business as an architect in 1924. Problems with showing the new "talking pictures" set the scene for Vivian Taylor becoming involved with the science of acoustics. From 1930 to 1941 his office was involved with the design and treatment of an incredible 434 theatres and public halls. Not only was H. Vivian Taylor an acoustician and architect, but also a painter and pianist. The dinner was also the setting for the announcement that Tibor Vass had been elevated to the grade of Fellow and Stephen Samuels has been awarded a Merit Award. Stephen's award was in recognition of being a Councillor for 15 years and a member of both the Victoria and NSW Division Committees for 20 years.



Graeme Yates announcing the President's Prize

At the closing session on Friday the President's prize was awarded to the co-authors of a paper entitled: "Vibrato Frequency and Phase Lock in Operatic Duet Quality". The prize was awarded to Melanie Duncan, Carol Williams and Gordon Troup. Their paper will be published in a future edition of Acoustics Australia.

Overall the conference was a great success and a credit to all involved in its organisation, especially Charles Don, Geoff Barnes and Keith Porter.

Proceedings are available from the Society at $50 plus postage. Please contact the General Secretary, PO Box 4004, East Burwood 3151, phone (03) 9887 9400.

NSW Meeting AGM and GST

On 30 September the NSW Division tried a new initiative by arranging a breakfast meeting at a central Sydney hotel. Although only around 20 attended, this was considered to be quite a successful format for a meeting.

After enjoying a hot breakfast the short Annual General Meeting was held. The usual reports were presented and then it was time for the elections of office bearers. The Chairman, Stephen Samuels announced that he would be not standing for election. He has served 10 years on the Victorian and 10 years on the NSW Divisional Committees and during that time has held many posts including being a Councillor for 15 years. The meeting strongly supported a vote of thanks to Stephen for his work for the Society. The other retiring members were re-elected along with Matthew Harrison for the vacant position.

Then followed by a presentation on the GST by Ken Thurtell, a Sydney accountant. He went through the time frame for the various tax changes over the coming years and discussed the non GST items including the apparent inconsistencies with food (eg canned vs glass etc). He stressed that it is important to register soon for an Australian Business Number (ABN) and that it is essential to spend time and money on training and good advice now so that all necessary accounting systems are in place by July 2000.

He also drew attention to possible cash flow issues for companies as the GST debits are payable within 14 days of lodgement of the quarterly statements. Preparation is essential and the key points for businesses are:

- Think supply
- Assume everything subject to GST
- Think recovery of credits
- Think GST as a PAYE
- Remember export has no GST
- Think timing of payment of the quarterly payments and their effect on cash flow.

Marion Burgess

STANDARDS AUSTRALIA Committee News

Three acoustics Standards have been published by Standards Australia in recent weeks.

AS/NZS 1270:1999, Acoustics—Hearing protectors (Committee AV/3, Acoustics, Human Effects) incorporates changes to the method for measurement of real-ear attenuation of hearing protectors which bring the Standard into close alignment with the corresponding technical provisions of ISO 4869-1:1990 Acoustics-Hearing protectors, Part 1: Subjective method for the measurement of sound attenuation. The revised Standard is modelled in large part on the corresponding sections of ANSI S12.6-1997, Methods for Measuring the Real-Ear Attenuation of Hearing Protectors and reflects the extensive research on which that Standard is based.

AS 2363:1999, Acoustics-Measurement of noise from helicopter operations (Committee EV/11, Aircraft and Helicopter Noise) provides methods for the measurement of noise from helicopter landing sites and helicopter overflights. It provides technical guidance for local planners, government agencies, and operators in calculating the acoustic environment near existing and proposed helicopter landing sites or routes as a result of helicopter operations.

AS/NZS 1276.1:1999, Acoustics-Rating of sound insulation in buildings and building elements, Part 1: Airborne sound insulation (Committee AV/4, Architectural Acoustics) is identical in technical content with ISO 717-1:1996. The term 'weighted sound reduction index (R_w)' is used rather than 'sound transmission class (STC)', which has traditionally been used in Australia and New Zealand. The Australian/New Zealand Standard incorporates two informative appendices which are intended to assist users who have traditionally used the STC rating system in making the transition to the R_w rating system. AS/NZS 1276.1 will be referenced in the Building Code of Australia by way of BCA Amendment 6 to be published by 1 January 2000. The related deemed-to-satisfy provisions in the BCA will be given in terms of R_w rather than STC.

Committee AV/4 is currently revising two other acoustics Standards referenced in the Building Code of Australia, namely, AS 2107-1987, *Acoustics—Recommended design sound levels and reverberation times for building interiors, and AS 1191-1985, Acoustics-Method for laboratory measurement of airborne sound transmission loss of building partitions.* It is anticipated that the new edition of AS 2107 will include recommendations regarding design sound levels in apartments, flats and units, in recognition of increases in high density residential living since the Standard was last issued. Changes in workplace activities and lifestyles will also be reflected in the updated guidance on design sound levels and reverberation times, with the inclusion of additional occupancies/activities such as call centres, shopping malls and food courts. The committee is currently modifying the public review draft (DR 99367) in response to the comment received. The revision of AS 1191 will take account of the relevant parts of the ISO 140 series, as well as the capabilities of existing test facilities in Australia. AV/4 plans to issue a draft for public comment in late 2000. Other topics under consideration by Committee AV/4 include sound attenuation of pipe lagging systems, a single number rating for sound absorption, and floor impact testing.

Enquiries about the above items should be directed to Jill Wilson, Projects Manager, Standards Australia, PO Box 1055, Strathfield, NSW 2135, tel (02) 9746 4821, fax (02) 9746 4766, e-mail jill.wilson@standards.com.au.

Environmental Performance

HB 145:1999 is a Handbook on Case studies -Environmental performance evaluation which has recently been released by Standards Australia. It provides examples from organisations undertaking environmental performance evaluation. The case studies cover a number of different sized organisations as well as government agencies.

ISO Standards on Line

Standards Australia has just opened a new webshop which lets customers immediately download any ISO Standard as an Adobe PDF file. There's also an option to order paper copies for delivery by post.

This is a world-first and Standards Australia believes it's months, if not years ahead of any similar service.

Around 12,000 ISO and joint ISO/IEC Standards can be downloaded from the shop. The full range of IEC Standards should be available early in 2000. Subscribers can charge purchases to their account or to a credit card. ISO Standards look a bit expensive in comparison to our own Australian Standards, but they are priced according to the ISO recommended retail price. But there is an extra 10% discount when customers use the download option. That makes us the lowest cost source of ISO standards anywhere.

The webshop is at
http://www.isostandards.com.au

Trends in Science Education

The Australian Council of Deans of Science (ACDS) representing 35 universities in Australia met in Canberra on October 6-8. The major agenda item was the receipt and consideration of its commissioned report on Trends in Science Education: Learning, Teaching and Outcomes 1989-1997. This report highlights the need for a scientifically trained workforce that will enable Australia to seize the advantages in already existing industries and those inherent in as yet still unrecognised areas of science and technology. Australia must grasp its opportunities by whole-heartedly embracing a knowledge-based economy, so clearly dependent on a strong Science and Technology sector.

The ACDS views with concern the decline of student numbers in both the Secondary and Tertiary sectors in the basic (enabling) sciences and mathematics now clearly demonstrated in this report and further elaborated in the accompanying paper, Who is Studying Science.

The ACDS in full Council resolved to take action in three principal areas.

* Enhanced and Continuing Monitoring of "Trends" in science
* Commentary on and Raising Awareness of Trends in Science
* Secondary School Teaching of the Enabling Sciences and Mathematics

The papers and other information can be found on the ACDS Website at www.acds.edu.au/issues.htm.

Scientists meet Politicians

On Wednesday, November 25, 170 scientists representing most of Australia's scientific and technological societies descended on Parliament House in Canberra to bring to the attention of parliamentarians some of the urgent issues facing the community. The occasion was organised by FASTS, the Federation of Australian Scientific and Technological Societies, and the AAS was represented by Neville Fletcher.

The half-day of individual meetings with some 130 parliamentarians was preceded by a day of briefings, at which the prominent issues were made the focus of attention for scientific participants, with the assistance of some senior bureaucrats and some interested MPs.

It is only fair to say that members of parliament were keen to meet with scientific participants and showed considerable interest in the arguments that were presented. Only time will tell whether we have been successful in putting our case.

Sweet Sounds?

The NSW Division has contributed to the prizes for a competition within the Double Helix Club. This Club is organised by the CSIRO with the aim to encourage interest of school children in science. For this competition a new type of instrument had to be designed.

The entries were varied, innovative - and loud! Kenny Cheong (Vic) sent an illustration of his 'cup guitar', a wooden base containing glasses of various sizes and shapes, with strings passing over the top of them - the deeper the glass, the lower the note of the string. The 'stringy tube' was invented by Mark Salib (NSW), who described a pipe that split into two tubes: one carried wind to strings and the other was played like a flute. Other winners were the 'dijersax' (Alex Northey, NSW), a mini, wearable pipe organ (Sam Levy, Qld) and Guy Baldwin's (NSW) Play Dome, an electronic stringed instrument. It just goes to show how many different ways there are to make a noise!

The NSW Division has agreed to sponsor an acoustic competition next year. Information about the Double Helix Club can be found on http://www.csiro.au

Queensland EPA

The Queensland EPA has some interesting web pages on noise including background information and links to legislation www.env.qld.gov.au/environment/environment/noisefeature/

WA Occupational Noise Update

Change in Exposure Standard.

On 1 September 1999 the exposure standard for occupational noise changed to an $L_{Aeq,8h}$ of 85 dB(A). [Regulation 3.45 of the Occupational Safety and Health Regulations 1996]. This brings all WA workplaces into line with the National Standard for Occupational Noise, which has now been adopted by all States and Territories except South Australia (where it is under consideration). At this stage, the standard for peak noise level remains unchanged at 140 dB(lin). This will be reviewed if the National Standard is changed to 140 dB(C).

Revised Entertainment Noise Code

A revised Code of Practice for Control of Noise in the Music Entertainment Industry was launched on 29 August 1999 at the start of WorkSafe Week. Hard copies are available from WorkSafe Western Australia (ph (08) 9327 8775) for $3.00 each and the Internet version is on the department website at www.safetyline.wa.gov.au.

The revision was mainly needed to bring the Code up to date with the present regulations and National Code. The opportunity was taken to simplify the layout and place the technical information in appendices.

Internet Resources

WorkSafe Western Australia has also added lots of information on practical noise control to its website, as well as updating the Directory of Noise and Vibration Control Services. To find these from the homepage (www.safetyline.wa.gov.au) click on "Solutions-Essentials", then "Noise and Vibration". Case studies provided by the Education Department have been added to those from the Construction and Metal Manufacturing Industries. Shorter one page "Solutions" can be found by clicking on "Solutions - Practical Solutions" then "Noise and Vibration". For the basic risk management approach to noise control, illustrated by real case studies, click on "Education-SafetyLine Institute" and follow the instructions to enrol (you only need to supply an e-mail address and password). Then look for the Noise Assessment and Control Course and the Noise Control Management lecture.

As WorkSafe WA is always keen to expand the information on the website, if you have any interesting case studies or solutions please contact Pam Gunn on ph: (08) 93278669 gunn@worksafe.wa.gov.au.

Pam Gunn

Eureka Prize

The University of New South Wales Eureka Prize for Scientific Research, valued at $10,000, is awarded for outstanding but under-appreciated curiosity-driven scientific research done in Australia by an Australian scientist under the age of forty. The work must be published in an internationally respected, externally-refereed scientific journal(s), book(s) or equivalent electronic publication(s). Submissions due by 11 February 2000

Information: rogerm@amsg.austmus.gov.au or http://www.austmus.gov.au/eureka

Science and Technology Award

The prestigious annual Clunies Ross National Science & Technology Award was introduced in 1991 by the Ian Clunies Ross Memorial Foundation. It has now honoured forty-six special Australians who have made an outstanding contribution to the application of science and technology for the benefit of Australia. Award recipients will be publicly honoured with a silver medal at a formal presentation and dinner to be held at Hotel Sofitel, Melbourne on Wednesday 29 March 2000.

More details from http://www.cluniesross.org.au

Award for Vipac

Vipac Engineers and Scientists were awarded an Engineering excellence award as well as the BRW Award for Industrial Development for their BAMbino. This instrument is the world's first portable Bearing Acoustic Monitor for accurate and easy detection of faulty idler bearings in conveyors. In the mining industry, conveyors can extend for many kilometres both above and under ground. A common reason for conveyor failure and belt damage is seized bearings in the idlers supporting the belt. The BAMbino uses advanced signal processing techniques to scan ambient conveyor noise to detect bearing faults and also ranks the faults severity.

Further information:
Vipac Engineers and Scientists,
tel 03 9647 9700, fax 03 9646 3427,
www.vipac.com.au

Product Directory

The Royal Australian Institute of Architects has recently set up a product directory on the internet at www.selector.com.au . This has an easy to use searching arrangement and will ultimately be a very valuable resource for those seeking products in the building industry. Simple listing of products is free and there is an annual cost for an enhanced listing.

Nutek Australia

ACU-VIB and Stantron, which are two well known firms dealing with acoustic instrumentation, have recently merged and formed a new company called NUTEK Australia. They will continue to offer their services and agencies.

The contact details for the new company are:
Unit 3, 10 Salisbury Rd, Castle Hill NSW 2154, PO Box 4760 North Rocks NSW 2151,
tel 02 9894 2377, fax 02 9894 2386.

Agilent and HP

Agilent is the company created by Hewlett Packard's plan to strategically realign itself into two fully independent companies and consists of HP's test and measurement, semiconductor products, chemical analysis and solutions businesses.

Further details: tel 1 800 629 485

New Agencies

Protector Safety Supply has recently announced that it can supply Ono Sokki integrating sound level meters and Larsen Davis personal noise exposure meters.

Further information: tel 02 8787 2911
fax 02 8787 2922

Victorian Meeting

On Sep 24, the Victorian Division held a meeting in one of the RMIT reverberation chambers. Entertainment was provided by a group of seven young singers (2 sopranos, 2 contraltos, baritone, and 2 basses) called *The Eternal Choir* who exploited the chamber's 5s reverberation time by vocalizing in harmony. In all they sang seven pieces starting with one based on one note and its octave to pieces with richer and more complex harmonies. It was a most interesting evening.

New Products...

YOKOGAWA
Signal Explorer

The Yokogawa Signal Explorer DL7100 is a 4 channel 500 MHz digital oscilloscope with a large TFT colour display, ample rate of 1GS/sec and very long memory. It has four analog inputs plus additional sixteen logic inputs available as an option.

An optional built-in printer records waveforms and other data and the DL7100 will, via the comms ports, also output to a colour printer and to a a PC for data viewing and reporting using the Yokogawa Waveform Viewer software.

Further Information: Yokogawa Australia,
02 9805 0699, fax 02 9888 1844,
measurement@ yokogawa.com.au

TMA
Coustone Cladding

Coustone has been developed for use where the control of sound is essential. It is constructed from bonded flint with scientifically designed air cavities and so offers a unique combination of absorption and attenuation. It has NRC up to 0.95 and noise reduction up to 46 dB. Load bearing with class 0 fire rating it is unaffected by water, steam, condensation and damp. It is manufactured in 500 mm square panels in either 14 or 28 mm thickness.

Further Information: TMA,
Tel 02 4739 9523 Fax 02 4739 9524

RION
Sound Level Meter.

The new Rion NL-06 sound level meter is now available in Australia. The NL-06 is an integrating type 2 meter designed for make environmental noise measurements easier. The meter measures Sound Pressure Level (Lp), Equivalent Continuos Sound Pressure Levels (Leq), Maximum (Lmax) and Minimum (Lmin) Sound Pressure Levels and Percentile Sound Pressure Levels (Ln) with 5 selectable settings. The NL-06 also has a built in memory card slot to provide an efficient means for the high speed transfer of data to a computer for off-line processing. This meter features a large internal memory - for example, when measuring Leq and Ln at 10 minute intervals, memory capacity covers a full fifty days.

Further Information: Acoustic Research Laboratories. Tel 02 9484 0800,
Fax 02 9484 0884 or
www.hutch.com.au/~acoustic

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An Acoustics Archive with abstracts of all significant acoustics papers published in the last five years, culled from over 280 journals will be produced on a single CD Rom. It will be fully searchable by keywords, title words, category, subject and author. A full text delivery service of compete papers will be available.

Further Information: Multi Science Publishing, Fax 44 1277 223 453,
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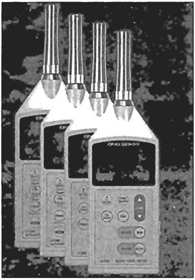
Type 2 Sound Level Meters - An Application-Specific Series

The LA-1200 Series from Ono Sokki



The new LA-1200 series from Ono Sokki offers application specific features from point & shoot measurements to environmental logging with RS-232C output and direct printer output capability.

The LA-1210 and LA-1220 with on-line function - ideal for general stationary sound level measurements; for weighted (L_A, L_C) and non-weighted (L_P) sound pressure levels.

The LA-1240 integrating sound level meter with memory - ideal for non-stationary industrial and work environment sound level measurements; for L_{eq}, L_E and L_X.

The LA-1250 integrating sound level meter for environmental measurements - ideal for road traffic sound level measurements; for L_{eq}, L_E and L_X. Back-erase function (max 10sec), internal memory (manual 300 addresses, each can hold 8 measurements and 4 parameters)

For further information, phone Vipac on:
1300 7 VIPAC (1300 7 84722)
or email to sales@vipac.com.au
http://www.vipac.com.au

VIPAC

Diary...

2000

*** February 7-9, SYDNEY**
Pacific 2000
Undersea Defence Technology
Details: http://www.udtnet.com

May 17-19, AALBORG
9th Int Meet Low Frequency Noise & Vibration
Details: W. Tempest, Multi-Science Publishing Co. Ltd., 5 Wates Way, Brentwood, Essex CM15 9TB, UK Fax: +44 1277 223453

May 24 - 26, ISTANBUL
Int Symp Noise Control & Acoustics for Educational Buildings and Turkish National Congress on Acoustics
Details: Turkish Acoustical Society, YTÜ Mim. Fak., 80750 Besiktas-Istanbul, Turkey; Fax: +90 212 261 0549; www.takder.org

May 30 - June 3, ATLANTA
139th Meeting of ASA.
Details: Fax: +1 516 5762377,
Web: asa.aip.org

June 5-9, INSTANBUL
Int Conf On Acoustics, Speech & Sig Proc
Details: Tülay Adali, University of Maryland Baltimore County, Department of Computer Science and Electrical Engineering, 1000 Hilltop Circle, Baltimore, MD 21250 USA; Fax: +1 410 455 3969; http://icassp2000.sdsu.edu/

June 6-9, ST.PETERSBURG
5th Int Symp Transport Noise & Vibration
Details: EEAA, Moskovskoe Shosse 44, 196158 St.Petersburg, Russia; Fax: +7 812 127 9323; noise@mail.rcom.ru

July 4-7, GERMANY
7th Int. Cong. on Sound and Vibration
Details: ICSV7, Congress & Seminar Management, Industriestrasse 35, D-82194 Groebenzell, Germany. Fax: +49 8142 54735 info@csm-congress.de, http://www.iiav.org

July 10 - 13, LYON
5th European Conf on Underwater Acoustics.
Details: LASSSO, 43 Bd. du 11 novembre 1918, Bat. 308, BP 2077, 69616 Villeurbanne cedex, France, Fax: +33 4 72 44 80 74; www.ecua2000.cpe.fr

August 23 - 25, NANJING
ACSIM 2000, 2nd Asia-Pacific Conf Systems Integrity & Maint.
Details: Anna Maltezos, Dept Mech Eng, Monash Uni, Caulfield East, VIC 3145, Australia. Tel: +61 3 9903 2335 Fax: +61 3 9903 1084; anna.maltezos@eng.monash.edu.au, http://www-mech.eng.monash.edu.au/

August 28-30, NICE
INTER-NOISE 2000
Details: SFA, 23 avenue Brunetière, 75017 Paris, France; Fax: +33 1 4788 9060; http://inter-noise2000.loa.espci.fr/

Aug 31 - Sep 2, LYON
Int Conf Noise & Vib Pre-Design & Charact. Using Energy (NOVEM)
Details:LVA, INSA de Lyon, Bldg. 303, 20 avenue Albert Einstein, 69621 Villeurbanne, France; Fax: +33 4 7243 8712 lva@insa.insa-lyon.fr http://lva.insa-lyon.fr/novem2000/

Sep 13-15, LEUVEN
Int Conf Noise & Vib Eng (ISMA 25)
Details: ISMA 25, K.U.Leuven Dept Mech Eng, PMA, Celestijnenlaan 300B, B-3001 Leuven, BELGIUM Fax (+32) 16 32 29 87, lieve.notre@mech.kuleuven.ac.be http://www.mech.kuleuven.ac.be/pma/events

Sept 17 - 21, VILNIUS
1st Int Conf (10th Anniversary).
Details: Acoustical Soc Lithuania, Kriviu 15-2, 2005 Vilnius, Lithuania; Fax: +370 2 223451; daumantas.ciblys@ff.vu.lt

October 3-5 KUMAMOTO
WESTPRAC VII
Details: Dept Computer Science, Kumamoto Uni. 2-39-1 Kurokami, Kumamoto, 860-0862. Tel: +81 96 3423622 Fax: +81 96 3423630 westprac7@cogfni.eecs.kumamoto-u.ac.jp http://cogni.eecs.kumamotou.ac.jp/others/westprac7

October 16-20 BEIJING
6th Int. Conf. on Spoken Language Processing
Details: ICSLP 2000 Secretariat, Institute of Acoustics, PO Box 2712, 17 Zhong Guan Cun Rd, Beijing 100 080, China, Fax: +86 10 6256 9079, mchu@plum.ioa.ac.cn

*** November 15-17, PERTH**
Acoustics 2000
AAS Conference
Details: AAS–WA, P.O. Box 1090,
West Perth, WA 6872,
barclays@iinet.net.au

December 4-8, NEWPORT BEACH
Meeting of the ASA
Details: ASA, 500 Sunnyside Blvd., Woodbury, NY 11797 USA. Fax +1 516 576 2377, web: asa.aip.org

2001

June 4-8, CHICAGO
141th Meeting of the Acoustical Society of America
Details: ASA, 500 Sunnyside Blvd, Woodbury, NY 11797-2999, USA, Fax: +1 516 576 2377, Web: asa.aip.org

Aug28 - 30, THE HAGUE
INTER-NOISE 2001
Details: secretary@internoise2001.tudelft.nl; Web: internoise2001.tudelft.nl

September 2-7, ROME
17th Int. Cong. on Acoustics
Details: A. Alippi, 17th ICA Secretariat, Dipartimento di Energetica, Universitá di Roma "La Sapienza", Via A. Scarpa 14, 00161 Roma, Italy, Fax: +39 6 4424 0183, www.uniroma1.it/energ/ica/html

September 10-13 , PERUGIA
ISMA 2001 ,
CIARM & Catgut Acoust Soc
Details: c/o "Perugia Classico" - Comune di Perugia, Via Eburnea,9, I-06100 Perugia, Italy, Fax: +39 75 577 2255, perusia@classico.it

WWW LISTING

The ICA meetings Calendar is available on http://gold.sao.nrc.ca/ims/ica/calendar.html

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Volume 27, 1999

AUSTRALIAN ACOUSTICAL SOCIETY ENQUIRIES

NATIONAL MATTERS

* Notification of change of address
* Payment of annual subscription
* Proceedings of annual conferences

General Secretary
AAS– Professional Centre of Australia
Private Bag 1, Darlinghurst 2010
Tel/Fax (03) 9887 9400
email: watkinsd@melbpc.org.au
http://www.users.bigpond.com/Acoustics

SOCIETY SUBSCRIPTION RATES

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Associate and Subscriber	$75
Retired	$31
Student	$21

DIVISIONAL MATTERS

Enquiries regarding membership and sustaining membership should be directed to the appropriate State Division Secretary

AAS - NSW Division
Professional Centre of Australia
Private Bag 1,
DARLINGHURST 2010
Sec: Mr D Eager
Tel (02) 9514 2687
Fax (02) 9514 2665
david.eager@uts.edu.au

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PO Box 1528,
MILTON 4064
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Fax (07) 3364 7477
rachel_carter@usrcorp.com

AAS - SA Division
C/–Department of Mech Eng
University of Adelaide
SOUTH AUSTRALIA 5005
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Fax (08) 8303 4367
cqhoward@mecheng.
adelaide.edu.au

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MELBOURNE 8007
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charles.don@sci.monash.edu.au

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Fax (08) 9222 7157
john_macpherson@environ.gov.au

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Acoustics & Vibration Centre, ADFA
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Fax (02) 6268 8276
email: acoust-aust@adfa.edu.au

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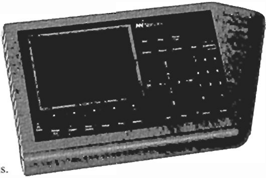
DATA ACQUISITION SYSTEMS

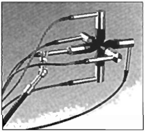
NORSONICS

Environmental Sound Analyser Nor-121



SPL All these values measured in parallel
L_{max} with all time constants (F, S and I) and
L_{min} with A-, C- and Flat-weighting.
L_{eq}
L_E Except for L_{peak} these functions may also
L_{peak} be measured in octave and 1/3 octave bands.

Measurement results and raw data may be stored on HD or standard PC card. The instrument may be operated in a stand-alone mode or be integrated into a comprehensive area noise monitoring system controlled over its computer interface.



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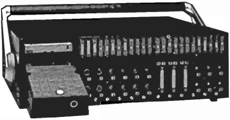
- Condenser microphones
- Outdoor microphone systems
- Intensity probes and calibrators
- Probe and Array Microphones
- New series of Hydrophones and associated preamplifiers



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ETMC Technologies

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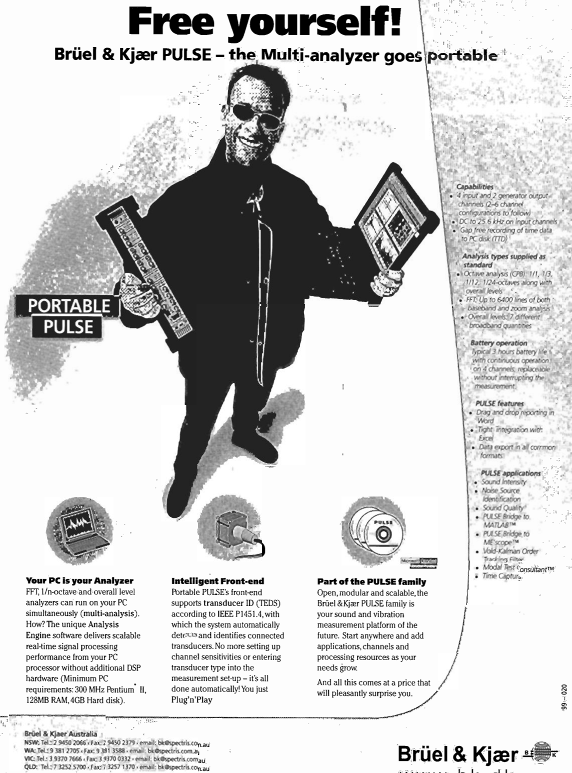

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PULSE

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- Tight integration with Excel
- Data export in all common formats

PULSE applications

- Sound Intensity
- Noise Source Identification
- Sound Quality
- PULSE Bridge to MATLAB™
- PULSE Bridge to ME'scope™
- Vold-Kalman Order Tracking Filter
- Modal Test Consultant™
- Time Capture

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