Institute of Acoustics

Special Issue:

Acoustics in Medicine

Technical Contributions

Acoustics in Medicine - An Introduction
Robert C Chivers FIOA
Ultrasonic Diagnostics and Imaging
Peter N T Wells
Doppler Techniques
Peter J Fish
Ultrasound Surgery
Gail ter Haar
Acoustic Disintegration of Kidney Stones
Andy Coleman

Consultancy Spotlight

Acoustics and Sound Control in UCI Multiplex Cinema Design
Vernon Cole MIOA

The Acoustics World

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Euronoise '92

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Obituary

Teodors Priede

acoustics BULLETIN

Volume 17 No 6
November-December 1992

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November-December 1992

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St. Albans, Herts. AL1 1PZ
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Oscar Faber Acoustics

Printed by:
Staples Press, Alban Park, Hatfield Road, St Albans

ISSN: 0308-437X
Single copy £7.00 Annual subscription (6 issues) £30.00

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The Institute of Acoustics was formed in 1974 through the amalgamation of the Acoustics Group of the Institute of Physics and the British Acoustical Society and is the premier organisation in the United Kingdom concerned with acoustics. The present membership is in excess of one thousand seven hundred and since 1977 it has been a fully professional Institute. The Institute has representation in many major research, educational, planning and industrial establishments covering all aspects of acoustics including aerodynamic noise, environmental, industrial and architectural acoustics, audiology, building acoustics, hearing, electroacoustics, infrasonics, ultrasonics, noise, physical acoustics, speech, transportation noise, underwater acoustics and vibration.

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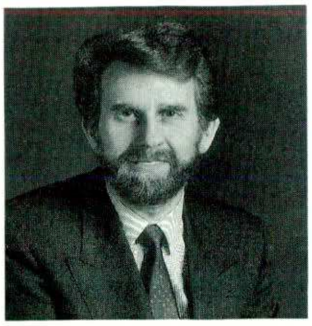

Dear Fellow Member

I write this upon returning from visiting the second of the two 1992 Windermere conferences. They were, it seems, great successes both numerically and in terms of their value to delegates. This is perhaps all the more encouraging in view of the severe recession we all know the country is suffering. There will be full reports in the next issue of the Bulletin.

As you will read in this issue, the Euronoise Conference held at Imperial College attracted delegates from all member states of the EC and representatives from Commission Directorates concerned with health and safety at work and the environment, placing the Institute's name at the forefront of European initiatives in noise control. You may not, however, immediately think this to be the case from the Minister's address which is reproduced verbatim in the conference report.

I am also pleased to tell you that agreement has been reached between seven of the acoustical societies of Europe to commence publication of Acta Acoustica. Despite its rather quaint title, the new journal will seek to publish scientific and engineering papers in any branch of acoustics, noise and vibration, predominantly, I expect, in the English language. In addition there will be a European version of the Bulletin's blue pages with news and announcements from societies, and information about related CEC programs. The founding national societies are keen to ensure that Acta Acoustica, which will be published six times a year commencing in mid-1993, will be of interest to a wide range of readers who are involved in the profession of acoustics. Council takes the view that the UK, as represented by the Institute, should participate actively in the project from within, rather than leave the other societies to develop the journal by themselves. Accordingly, Council has agreed that limited support will be given to the project for the first two years of publication.

If you wish to receive a personal copy of Acta Acoustica throughout 1993/94, contact the Secretariat for further information. The personal subscription price, which is available only to members for their personal use, is approximately £30-35 for six copies of some 200 pages each. If you wish to consider publishing in Acta Acoustica, information for authors is also available from the Secretariat.

Council gave permission for the Education Committee to set up a Certificate in Environmental Noise Measurement along the lines of the Certificate of Competence already established in Work-place Noise Assessment. Council also charged that committee with exploring alternative teaching strategies for the Diploma. This is because staffing changes in Accredited Centres are starting to leave significant areas of the country without provision.

With best wishes

Yours sincerely

Peter Wheeler.

ACOUSTICS IN MEDICINE - AN INTRODUCTION

Robert C Chivers FIOA

Ultrasonics as a subject has grown by a synergistic interaction of two branches of technology: that of transducer materials and that of electronic devices. The discovery of the piezoelectricity of quartz by the Curie brothers opened the possibility of creating ultrasonic vibrations in principle in 1880. In reality it was necessary to wait until de Frost's triode valve in 1903 and the subsequent development of electronic oscillators before experimental investigations could start. In the late 1950's the introduction of piezoelectric ceramics gave ultrasonic transducer construction a new dimension of flexibility, although the introduction of solid state electronics in the form of the transistor took rather longer to take effect. Only just over 20 years ago the driving circuits for many ultrasonics applications were still based on vacuum tubes [1]. The revolution in electronic miniaturisation and in the introduction of high speed (wide bandwidth) devices has had the effect, at the ultrasonic frequencies used in diagnostic medicine, of transforming procedures and techniques that appeared once to be limited to research laboratories into components of portable interactive clinical equipment.

The historical development of medical ultrasonics has been well summarised by Hill [2]. It is interesting to note that while the early enthusiasm was for therapeutic applications, the overwhelming emphasis of activity in recent years has been in diagnostic instrumentation. It appears that this has been driven by the technological developments mentioned above. It is not clear that these instrumental transformations have either been based on or been complemented by improved scientific insights of comparable scale with regard to the basic interactions between the ultrasonic waves and the biological structures of interest. In very recent years there has been a renewed interest in those medical applications in which it is the purpose to change the tissue with the ultrasonic wave, rather than to change the ultrasonic wave with the tissue.

The UK has played a prominent role internationally in the development of medical ultrasonics and I feel that we are fortunate in having been able to persuade four of the leading international experts in their specialities to introduce these specialities and give some idea of the current state of the art. Professor Peter Wells from Bristol discusses diagnostic imaging procedures and Dr Peter Fish from Bangor describes the way in which Doppler techniques for blood flow measurement can complement the anatomical imaging methods. It is perhaps relevant to say that ultrasonics is one of very few real-time imaging techniques available to the clinician. Thus these authors are at a significant disadvantage in being only able to illustrate their contributions with still photographs. In the manner of the prologue to an Elizabethan play 'think, when I speak of babies moving and hearts beating that you see the signs of motion and coursing blood of living organs'.

To complement these papers Dr Gail ter Haar of the Institute of Cancer Research at Sutton reviews surgical applications of ultrasound and Dr Andy Coleman from St Thomas's Hospital describes how ultrasound is being increasingly used in stone disruption in vivo. It is hoped that further contributions may appear in future editions of the Bulletin on applications in Physiotherapy and in Tissue Characterisation.

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ULTRASONIC DIAGNOSTICS AND IMAGING

Peter N T Wells

Introduction

During the last thirty years, ultrasonic diagnosis has become essential in the practice of modern medicine. Ultrasonic pulse-echo techniques provide high quality images in real time of structures such as the heart, blood vessels, abdominal organs and the fetus. Furthermore, ultrasonic Doppler methods can be used to obtain information about blood flow and structure motion: this is discussed by Dr Peter Fish in the following article.

At the levels of exposure and dosage used in contemporary techniques, ultrasound seems to be safe. Real-time ultrasonic imaging is an interactive process that provides three-dimensional information about structure and function. It is important to understand that ultrasonic imaging does have its limitations: in particular, it is not suitable for examining bony or gas containing structures. This is because bone reflects and strongly attenuates ultrasound, and gas is an effective barrier to transmission because of its low characteristic impedance. Of course, there are many other methods of medical imaging, including traditional radiography, X-ray computed tomography, radionuclide scanning and magnetic resonance imaging. In clinical situations in which more than one of the available methods could provide the diagnosis, ultrasound is usually the wisest choice [1] because it is safe, noninvasive, real-time and relatively inexpensive.

Ultrasonic imaging owes its origins to the pioneering work carried out in the 1950s by Douglass Howry in Denver [2] and John Wild and Jack Reid in Minneapolis [3]. The great potential of the clinical applications was first demonstrated, however, by Ian Donald and Tom Brown in Glasgow [4]. Ian Donald was Regius Professor of Midwifery in the University of Glasgow who already had an international reputation as an obstetrician when he began his collaboration with Tom Brown, an engineer with the now-defunct Kelvin Hughes Company, in the late 1950s. This collaboration was enormously fruitful and, looking back, it was the remarkable achievements of the Glasgow group that first demonstrated the feasibility of many of the techniques which have since revolutionised the care of the pregnant woman and the unborn baby.

Principles of Pulse Echo Ultrasonic Imaging

Ultrasonic pulse echo imaging is based on the well-known principles [5] employed in radar and sonar. An ultrasonic pulse is generated by electrical excitation of a piezoelectric transducer, the aperture of which in relation to the wavelength determines the shape of the ultrasonic beam. The speed of ultrasound in water and the soft tissues of the body is about 1500 ms^{-1}, so that the wavelength is about 1.5 mm at a frequency of 1 MHz. The ultrasonic pulse is reflected or scattered where there are discontinuities in characteristic acoustic impedance (equal to the product of the density of the material and the speed of ultrasound within it) along the ultrasonic beam. There are small changes in characteristic acoustic impedance at the boundaries between the different tissues of the body, and within the tissues themselves, which give echoes which are detected by the same transducer that was used to transmit the ultrasonic beam. Thus, the transducer is used directionally to explore the inside of the body by detecting echoes delayed in time according to their depths.

The pulse echo information can be displayed on an oscilloscope as a trace in which depth is represented on the time axis and the presence of reflecting structures along the beam gives rise to deflexions of the trace. Alternatively, the timebase can be brightness-modulated by returning echoes. Then, by linking the direction and position of the timebase on the display to the direction and position of the ultrasonic beam across the patient and scanning the beam in a plane, a two-dimensional image of the scanned section is produced.

Ultrasonic Transducers

The transducer converts electrical signals into ultrasound for transmission into the patient and it produces electrical signals corresponding to the ultrasonic field resulting from the effects of tissue on the interrogating beam. Thus, the transducer is the key component in any medical ultrasonic imaging system.

Medical diagnostic ultrasonic transducers in current use almost all employ ferroelectric ceramics [6]. These ceramic materials have very high piezoelectric and mechanical coupling coefficients. This means that they are good transmitters and receivers of ultrasound. The receiving sensitivity is particularly important because this determines the ultrasonic intensity necessary to produce detectable echoes and, consequently, controls the ultrasonic exposure conditions which are relevant to the possibility of hazard. Unfortunately, ferroelectric ceramics have characteristic acoustic impedances that are substantially higher than those of water and biological soft tissues. To minimise the problem of acoustic mismatch, impedance matching layers are used to exploit the inherent sensitivity of the ceramic and to allow broadband operation. The simplest form of impedance matching layer has an impedance which is equal to the geometric mean of the impedances of the transducer and the load, and a thickness of one quarter wavelength. Such a matching layer is rather frequency-selective, however, and modern transducers have multiple matching layers to minimise this problem [7].

Various types of ultrasonic transducers are in routine clinical use. They include single-element disks (often concave to provide weak focusing and sometimes fitted with plastic lenses), annular and linear arrays. The annular arrays may be up to about 100 mm long, with up to about 300 elements. These long arrays may be flat or curved. A flat array produces a scan with a rectangular format, whereas a convex array provides a kind of sector scan. Short linear arrays, typically around 10 mm long with up to about 100 elements, are also commonly used as phased arrays to produce sector scans [8].

Although ferroelectric ceramics are very satisfactory transducers, they do have important limitations. The ceramic materials inherently have high Q factors and they are prone to complex resonance modes. This means that, when used to produce short pulses (necessary for high resolution), the transducer is inclined to ring with significant amplitude for quite a long time following the production of the pulse. This limits the dynamic range of the transducer and the principal effect of this is to reduce the contrast resolution of the imaging system. Also, the performance of ceramic transducers deteriorates when the beam is steered away from the central axis of the array, mainly because this changes the effective thickness of the transducer.

Because of the limitations of ferroelectric ceramics, there is now great interest in the possibility of using plastic transducer materials in medical diagnosis. Polyvinylidene difluoride and its derivatives [9] have much lower characteristic acoustic impedances than the ceramics and so provide a good match to water and soft tissues without the need for intermediate acoustic matching layers. They also suffer less from multiple mode resonances and this is an important advantage particularly when operating off-axis in an array. The main disadvantage of the piezoelectric plastics is that they are less sensitive than the ceramics. They also have a relatively low dielectric constant and so require large driving voltage and this also gives rise to poor noise performance. Recently, the performance of the piezoelectric plastics has been overtaken by the development of piezoelectric composite materials. These composites consist of a plastic polymer substrate within which small particles of ferroelectric ceramic are embedded. Ideally, the piezoelectric ceramic is in the form of minute rods aligned along the thickness of the sheet. Piezoelectric composites combine the low acoustic impedance advantage of plastic transducers with the high sensitivity and low electrical impedance advantages of ceramics [10] and they are relatively free from lateral mode resonance effects [11]. They are just beginning to be used in advanced commercially-available scanning machines.

Specialised Transducer Probes

Most ultrasonic imaging is carried out using an ultrasonic probe in contact with the patient's skin. The only preparation that is required is to apply a light coating of an innocuous air-excluding coupling gel to the skin. The method is completely noninvasive and the patient experiences no discomfort; indeed, it is often an informative and even pleasurable experience, especially for the pregnant patient, to be able to see the real-time images and to discuss what they show with the doctor or radiographer carrying out the investigation.

There are some situations, however, in which the usefulness of ultrasonic imaging can be greatly enhanced by the use of specialised transducer probes that can be positioned closer to the structure to be examined than would be possible by using a probe in contact with the patient's skin. This allows higher frequencies to be employed. This is because the depth of penetration through intervening tissue is thereby reduced; the attenuation in tissue increases with the frequency, so that higher frequency can be used with the same overall attenuation. Higher frequencies result in better resolution and the possibility of using smaller transducers.

There are several natural cavities in the body into which suitably designed probes can be introduced directly from the outside. Such probes have been designed for the oesophagus, the vagina and the rectum. For example, the heart can be visualised from the oesophagus without the problems caused by the ribs and the lungs when a probe is placed on the chest. Intravaginal scanning allows close access to the uterus and excellent imaging of the early pregnancy. An intrarectal probe can be used to examine the bowel wall to allow the early detection and assessment of malignant tumours and it also provides excellent access to the prostate which is otherwise difficult to image because of its position in the bony pelvis and neighbouring gas containing structures.

In addition to intracavitary scanning, probes are available for imaging from the insides of blood vessels. These miniature catheter-mounted transducers may be mechanically driven or the beam steering may be achieved by means of tiny arrays [12]. One such commercially-available array has 64 elements arranged in a cylinder with a diameter of only 2 mm, mounted at the tip of a long flexible catheter. Specially-designed integrated circuits are connected directly to the piezoelectric plastic transducer elements so that the problem of the high electrical impedance of the transducers is minimised by the avoidance of the relatively high capacity of long electrical connexions. Typically, intravascular imaging devices operate at frequencies of up to around 20 MHz, have penetrations of about a centimetre and can produce images with resolutions of about a tenth of a millimetre.

Recent Advances in Pulse Echo Imaging

The quality of an image can be described in terms of its spatial, contrast and temporal resolutions. The noise and the presence of artifacts are also relevant. In medical pulse-echo ultrasonic imaging, the system designer has to begin by specifying the dimensions of the tissue slice (or volume) that is to be examined. The speed of ultrasound in tissue (about 1500 ms^{-1}) then determines the time necessary to obtain a single line of pulse-echo image information. For example, 200 μs is needed to transmit a pulse and receive the echo from a target at a range of 150 mm. A complete image consists of a number of lines of ultrasonic pulse-echo information distributed side-by-side throughout the image plane. Thus, there is a compromise between the number of lines per frame and the image frame rate. For the example being considered, with a penetration of 150 mm, there could be a maximum of 5000 lines per second so that there might be 50 lines in an image at a frame rate of 100 per second, or 100 lines at 50 per second, and so on. Only by collecting several lines simultaneously [13] can the performance be improved; the limited bandwidth due to the dispersive attenuation of tissue effectively precludes the use of pulse-coding techniques as an alternative strategy.

The system designer, having specified the required penetration, next seeks to select the highest possible ultrasonic operating frequency. This is because the highest frequency has the shortest wavelength and so is likely to provide the best spatial resolution. The attenuation of ultrasound in soft tissues ranges from about 0.15 dB cm^{-1} at 1 MHz in blood to 1.5 dB cm^{-1} MHz^{-1} in fat [14], with a mean value of around 0.5 dB cm^{-1} MHz^{-1}. As the frequency is increased, the echo amplitude from a target at the maximum depth decreases. The amplitude of the echo from the deepest target has to have an adequate signal-to-noise ratio to allow it to be detected and displayed and this controls the maximum frequency that can be used. With modern transducers employing ferroelectric ceramics, the frequency is typically 3-5 MHz for abdominal and cardiac imaging, 5-8 MHz for examining structures close to the skin surface such as the thyroid and the peripheral blood vessels and for intravaginal and intrarectal scanning, and 10-12 MHz for high resolution imaging of the eye.

Ultrasonic imaging systems have signal processing which provides compensation for attenuation in the tissues. This can be achieved by increasing the gain of the receiver with time following the transmission of the ultrasonic pulse so that targets with similar scattering characteristics produce similar registrations on the display independent of depth. This signal processing technique is known as swept gain, or time gain control. The development of broadband transducers, however, has made an alternative technique possible. Rather than changing the receiver gain with depth, the centre frequency of the receiver passband can be swept down with depth so that the higher frequency components of the transmitted pulse produce the information in the image close to the probe, whilst the lower frequency components, which are less attenuated, produce the deeper image information. This means that, although the resolution deteriorates with increasing depth, it is optimised throughout the entire image plane [15].

The spatial resolution of the imaging system generally increases with the ultrasonic frequency but this may not be the case if the medium being imaged is inhomogeneous.

Compared with a transducer operating at lower frequency, a high frequency probe with the same dimensions has a longer near field and less divergence in the far field. As the size (or aperture) of the transducer is reduced, the length of the near field reduces and the far field divergence increases. The width of the beam can be reduced by focusing in the near field to improve the lateral resolution and, as has already been mentioned, this can be done either by means of a concave transducer, with a lens or with appropriate control of a transducer array. The position of the focus has to be fixed on transmission, but with an array it is possible to sweep the delay times so that the position of the receiving focus moves along the beam axis and is always coincident with the instantaneous source of echoes [16]. A more economical compromise, often used in less expensive scanners, is to switch the position of the focus between a small number of discrete zones. It is interesting to note that the swept frequency technique for attenuation compensation and resolution optimisation that has already been described is associated with a relatively higher exposure of ultrasound to the superficial tissues. Consequently, if the depth at which optimum resolution is required to reveal information of diagnostic importance is known in advance, the exposure can be minimised by choosing the appropriate frequency and aperture, and using switched selection of the position of the focal region.

In principle, for a fixed frequency of operation, constant beamwidth at the focus is provided by using a receiving aperture with a constant f-number. This can be achieved with an annular array in which the aperture is arranged to expand with time following the transmission of the ultrasonic pulse [17].

Real tissues are inhomogeneous both in speed and attenuation and some tissues are significantly anisotropic [14]. Quantitative measurement of the effect of tissue inhomogeneity on the shape of an ultrasonic beam is not a simple matter. Typically, a beam may be deviated by 5 mm over a tissue distance of 50 mm [18]. An alternative (and generally more helpful) approach is to measure the root-mean-square phase aberration due to tissue inhomogeneity across the receiving aperture. This is typically around 30 ns for an aperture of 15 mm and a tissue path length of 50 mm [19].

Although several attempts have been made to compensate for tissue inhomogeneity [20, 21], it is important to realise that the tissue does impose an envelope on achievable ultrasonic imaging [22]. The only realistic prospect for increasing the size of this envelope seems at present to be through the use of a two-dimensional transducer array. In principle, such an array could have individually-adjusted compensation in the signal path associated with each of the elements in the array, to eliminate the effects of phase aberration and echo amplitude variation.

Apart from the problem of constructing and operating such an array, there is an important acoustical problem. Ideally, for the case of a single target in the ultrasonic beam, compensation could be optimised by a control system using the maximisation of echo amplitude as the criterion. Real tissues do not consist of single isolated scatterers sparsely distributed in a homogeneous continuum and so in practice this approach cannot be used. Work is going on with experimental two-dimensional arrays in which maximum speckle brightness is used as the optimisation criterion [21] and early results have been encouraging.

Tissue Characterisation and Image Texture Analysis

For years, scientists and clinicians have sought to devise ultrasonic techniques that would allow the histological and pathological characteristics of tissues to be identified from ultrasonic information [23]. If this was possible, much guesswork would be eliminated from ultrasonic diagnosis and, indeed, there would be no need for invasive procedures such as the removal of tissue specimens by means of small needles for microscopic study. Sadly, however, the search for ultrasonic tissue characterisation has been disappointing and in retrospect this is hardly surprising. Many years ago, Ian Donald likened the problem to that of trying to establish the goodness of an egg by looking at its shell! Even today, pathologists often argue about the diagnosis when they can see the tissues under their microscopes. How much more difficult must it be to be decisive when remotely probing by ultrasound!

It should be recognised that radiologists, when they look at ultrasonic scans, are often very good at identifying the nature of the tissues being examined. They can do this partly because they have knowledge based on experience of the likely choices in known anatomical relationships and the clinical condition of the patient and partly because the image texture does convey some information about the tissue scattering characteristics. Of course, image texture is the result of the properties of the imaging system to the extent that it is, in reality, simply a speckle pattern. The geometry of the speckle, however, also depends on the dimensions and power of the scattering structures within the tissue [24-26].

Sometimes, it has been argued that speckle is an artifact that should be suppressed. One of the most promising techniques for speckle suppression depends on adaptive filtering [27]. There is still controversy over the merits of this approach, however, and manufacturers do not yet offer speckle reduction as an image processing option. At the moment, a conservative approach would be to have a scanner with two image displays, one of which would show the traditional speckly image whilst the other would be speckle reduced.

Three-Dimensional Display

Current clinical applications of ultrasonic imaging are mainly based on the real time display of two-dimensional sections of the human body. Much of the skill required for successful interpretation involves the ability to relate such two-dimensional images to the three-dimensional anatomy which they represent. Recently, there has been growing interest in techniques for acquiring sets of two-dimensional images from three-dimensional volumes and for displaying the information on computer-based three-dimensional image processing workstations [28]. Essentially, there are two different approaches to three-dimensional display. In principle, the simplest approach requires segmentation of the image information for the display of three-dimensional surfaces. This approach is very successful when segmentation is reliable, as in the separation of bony and soft tissue structures in X-ray computed tomography [29]. With ultrasonic images, however, it is often difficult automatically to define the boundaries between organs and structures and more success has been achieved with volume rendering, which is

Fig. 1. An ultrasonic image of an unborn baby at 32 weeks of pregnancy. The baby's head can be seen on the right of the image, facing upwards; the placenta is the uniform grey structure attached to inside of the uterus at the upper left. The baby's fingers and thumb are in transverse section just above its mouth; part of the baby's spine is also visible. This scan was made using an advanced instrument manufactured by Toshiba Medical Systems.

the alternative approach to three-dimensional display [30]. Each volume element within the acquired three-dimensional data block is assigned an opacity and a brightness depending on its scattering characteristics so that a two-dimensional representation of the three-dimensional object can be provided from any viewpoint, positioned either outside or within the data block. Ingenious methods have been developed for acquiring the information and the main problem is that, because the speed of ultrasound is only 1500 ms^{-1}, the time of acquisition is likely to be at least a few seconds so that three-dimensional imaging can hardly be achieved in real time.

Conclusion

Nowadays, ultrasonic diagnostics and imaging are in routine clinical use not only in hospitals but also in clinics and even in the surgeries of general practitioners. An example of a modern high-quality ultrasonic scan is shown in Figure 1. Although more examinations are still carried out using X-rays, ultrasonic investigations come second in number in the UK and, in North America, ultrasonic imaging provides the largest component of the fees earned by radiologists. Current research aimed at improving ultrasonic imaging is mainly concerned with fundamental studies of ultrasonic beam propagation in tissues, approaches to reducing the effects of tissue inhomogeneity on image quality, the development of new piezoelectric materials and techniques for transducer fabrication, and three-dimensional display. During the next few years, dramatic advances can be expected in what is already established as one of the most important methods of clinical investigation.

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DOPPLER TECHNIQUES

Peter J Fish

Introduction

The frequency of ultrasound reflected or scattered from moving objects undergoes a Doppler shift proportional to the velocity of movement of the object, and this effect is used in Doppler instruments to detect and analyse movement of tissues within the body. Similar constraints on transmitted frequency - that is to say the requirement of projecting a narrow ultrasound beam from a small transducer, and the increasing attenuation with frequency, offset to some degree by increasing backscatter - apply in Doppler devices as in imaging instruments, and lead to transmitted frequencies in the range 2-10 MHz. This means that Doppler shift frequencies arising from typical reflector/scatterer velocities of 2-200 cm/s are in the audible range. A signal with the Doppler shift frequency can be obtained by beating transmitted and received signals together, and in the simplest Doppler instruments - transmitting and receiving ultrasound continuously on separate transducers mounted in a single probe - detection and limited analysis of tissue movement is carried out by listening to the Doppler signal on a loudspeaker or earphones. Such an instrument is used routinely to detect the foetal heart beat for example.

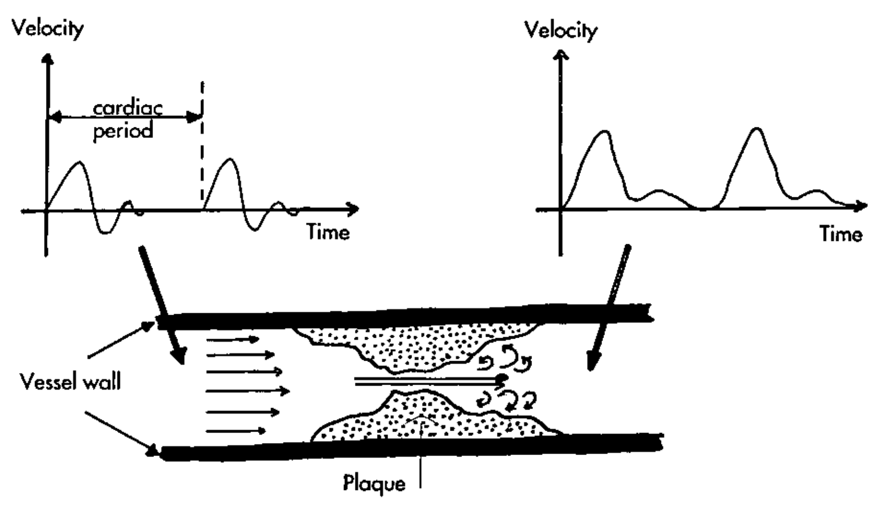

Fig. 1. Artery with plaque

However, the area of use which makes most of the capabilities of Doppler ultrasound is the detection and monitoring of blood vessel disease and the measurement of haemodynamics. In this case the Doppler shifted ultrasound is that backscattered from red blood cells.

The clinical problem is illustrated in Figure 1. Plaque and/or thrombus on the wall of the blood vessel forms a stenosis or reduction in vessel lumen. In the worst case the vessel may be blocked completely. Severe stenoses reduce flow and blood pressure downstream and, even when of insufficient size to be flow reducing, may shed small particles as a result of the pulsatile nature of blood flow in arteries and flexing of the blood vessel wall. These particles can embolise or block small vessels downstream. Typical clinical problems are pain when walking as a result of reduced and inadequate blood supply to leg muscles, embolisation of small vessels in the brain leading to a stroke, and reduction of blood to the heart muscles leading to angina or heart attack. Doppler ultrasound is used to find stenoses by detecting the increased blood velocity in the narrowed section of the blood vessel and in the emerging jet, by detecting vortices and turbulence induced by the protrusion into the vessel lumen and the change in blood velocity waveform resulting from the combination of an increased resistance to flow through the stenosis and the elastic nature of the vessel wall.

In addition, since plaque is found predominantly at the sites of vessel branching where the velocity field is particularly complex, and it is known that metabolite transport across the vessel wall is influenced by blood velocity shear, Doppler ultrasound has been useful in the investigation of the formation and progression of vessel disease.

The Doppler effect has been used in combination with pulse-echo imaging to monitor blood flow at operator-selected sites in the imaged blood vessel system and, by detecting Doppler shift in pulses backscattered from blood, to display flowing blood in colour, superimposed on the grey-scale anatomical image.

The Doppler Equation

The frequency (f_d) of the Doppler signal from a single scatterer moving with velocity $\bar{v}$ is proportional to the

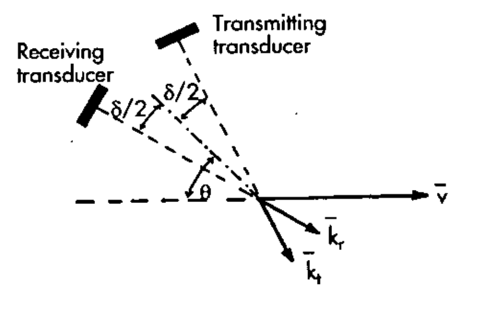

Fig. 2. Ultrasound beam/velocity vector geometry

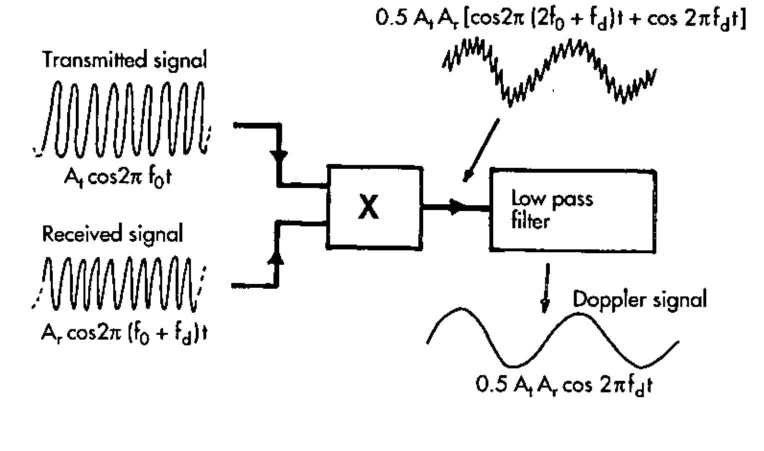

Fig. 3. Doppler demodulator

scatterer velocity, and the cosines of the angles between the direction of movement and the wave vectors ($\bar{k}_t$ and $\bar{k}_r$) of the ultrasound fields of the transmitter and receiver transducers (Figure 2). That is:

$$\begin{aligned} f_d &= -(1/2\pi)\,(\bar{k}_t + \bar{k}_r)\cdot v \\ &= -(v/\lambda)\,(\cos(\theta + \delta/2) + \cos(\theta - \delta/2)) \\ &= -(2vf_0 \cos\theta \cos\delta/2)/c \qquad (1) \end{aligned}$$

where

f_0 = transmitted frequency

c = speed of ultrasound and $v << c$.

The negative sign indicates that the Doppler shift is negative (transmitted frequency shifted to a lower frequency) if the direction of movement is in the conventionally positive direction (away from the transducers).

The angle δ between the beams is usually sufficiently small that $\cos\delta/2$ is close to 1.0. In pulsed Doppler instruments (described later) the same transducer is used for transmission and reception and $\delta = 0°$ (ie $\cos(\delta/2) = 1$). Thus the above equation may be simplified in both cases to

$$f_d = -(2vf_0/c)\cos\theta \qquad (2)$$

Note that there is no Doppler shift ($f_d = 0$) if $\theta = 90°$ (ie $\cos\theta = 0$), and the Doppler shift increases as θ decreases from 90° to 0°.

Doppler Signal Extraction

A signal with the Doppler shift frequency is obtained from a Doppler demodulator which mixes the received signal and a reference signal at the transmitted frequency in a non-linear device (usually a multiplier), and low-pass filters its output to remove signal components at the transmitted frequency and above (Figure 3).

Continuous Wave (CW) Doppler Instrument

The simplest ultrasonic Doppler instrument, the continuous wave or CW device is shown in block diagram form in Figure 4. Two piezo-electric transducers - one used for transmitting and the other for receiving - are mounted, as shown, in a probe. The transducers are PZT plates, usually rectangular or semi-circular, operating in the thickness mode at resonance. Unlike those used in pulsed imaging instruments, the transducers are normally air backed and therefore have high Q. The ultrasound beams from the two transducers are arranged to overlap such that the instrument is sensitive to movement within the region of overlap, known as the sensitive beam. The transmitting transducer is connected to an oscillator operating within the 2 - 10 MHz region and transmits ultrasound continuously. Ultrasound reflected and backscattered from tissue interfaces is picked up on the receiving transducer, and the electrical signal from the transducer amplified and passed to a Doppler demodulator. The Doppler signal from the demodulator is passed to an audio amplifier and filter, and then on to loudspeaker or headphones for audio interpretation and to some means of frequency analysis.

The ultrasonic signal picked up on the receiving transducer consists not only of the back-scattered ultrasound from blood cells, but also reflected ultrasound of much greater amplitude from other tissues such as the vessel wall. These signals are typically 40 dB greater than those from blood. These large amplitude signals themselves will often exhibit a low frequency Doppler shift because of the movement of reflecting tissues in the case of pulsatile arteries, or movement of the hand-held probe with respect to stationary reflectors. High-pass filtration is

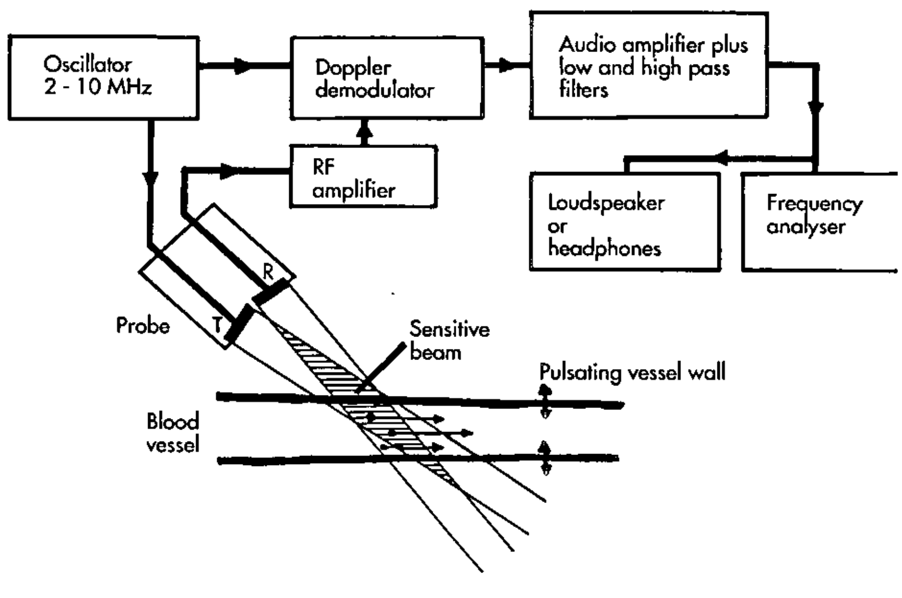

Fig. 4. Continuous wave instrument: T and R - transmitting and receiving transducers

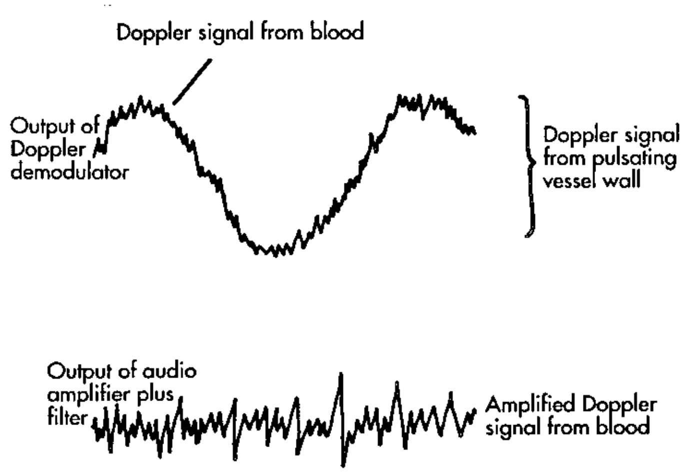

Fig. 5. Doppler signal before and after low pass filtration and amplification

included in the low-frequency amplifier to remove these high amplitude low-frequency Doppler signals. The filtration must take place at the input of the amplifier or after only a small amplification, otherwise these signals saturate the amplifier. The cut-off frequency of the filter is typically 200 Hz. An unavoidable side-effect of this filtration is the loss of low-frequency Doppler signals from slowly moving blood. Low-pass filters are included in the low-frequency amplifier in order to restrict the bandwidth of the amplifier and so keep electronic noise power to a minimum. The upper cut-off frequency is set to the highest Doppler shift frequency anticipated.

Since there is a range of blood velocities within the blood passing through the sensitive beam of an instrument, and the ultrasound is back-scattered from a random collection of blood cells, the Doppler signal is a random signal with a frequency spectrum reflecting this range of blood velocities. The form of the Doppler signal at the output of the Doppler demodulator and after amplification and filtration is shown in Figure 5.

The simple instrument shown has no ability to discriminate between directions of blood flow. Since flow direction is often important, and indeed, in many arteries the blood velocity changes direction at least once during the cardiac cycle, flow direction discrimination is incorporated in all but the simplest devices. There are basically two methods to preserve information on flow direction and these are illustrated in Figure 6. In the first the received signal is mixed in the Doppler demodulator, not with a signal at the transmitted frequency but at the transmitted frequency shifted by a frequency offset. In this case flow towards and away from the transducers is indicated by a Doppler signal frequency that is greater than or less than the frequency offset. In the second method the received signal is mixed with two reference signals at the transmitted frequency, one being 90° phase shifted with respect to the other. In this case two Doppler signals are generated. There is a phase difference of 90° between the frequency components of the Doppler signals arising from the two demodulators, and the direction of phase shift indicates the direction of flow.

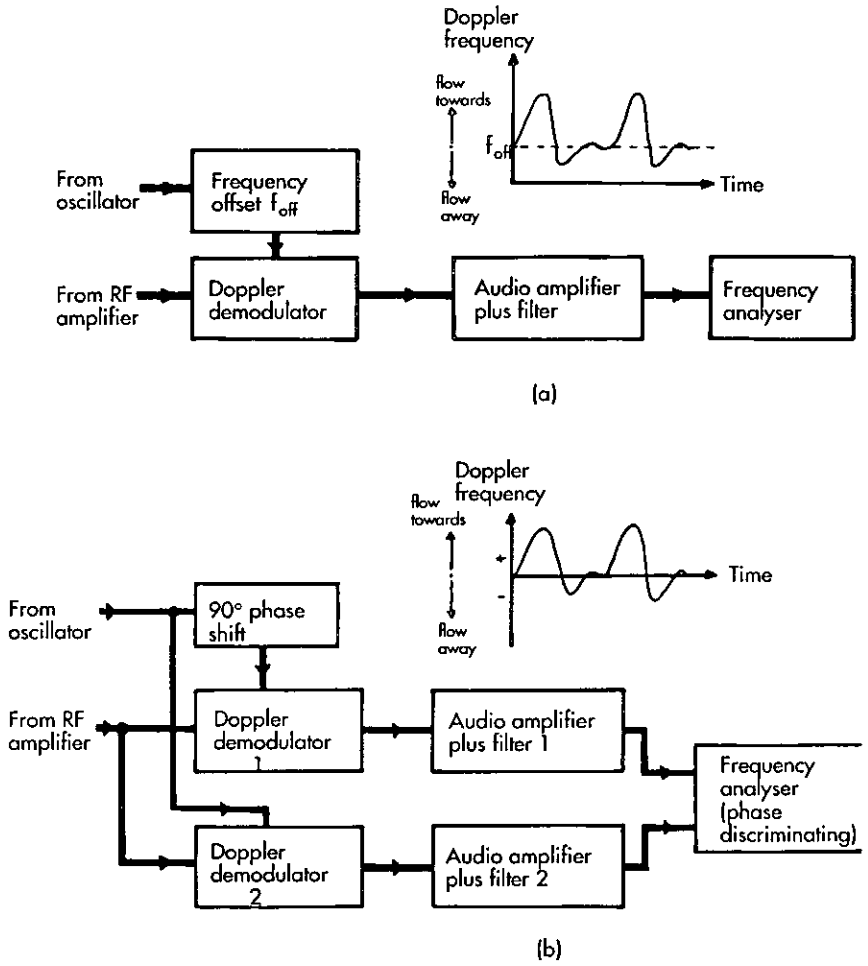

Fig. 6. Flow direction discrimination by
(a) offset reference frequency and (b) phase-quadrature demodulation

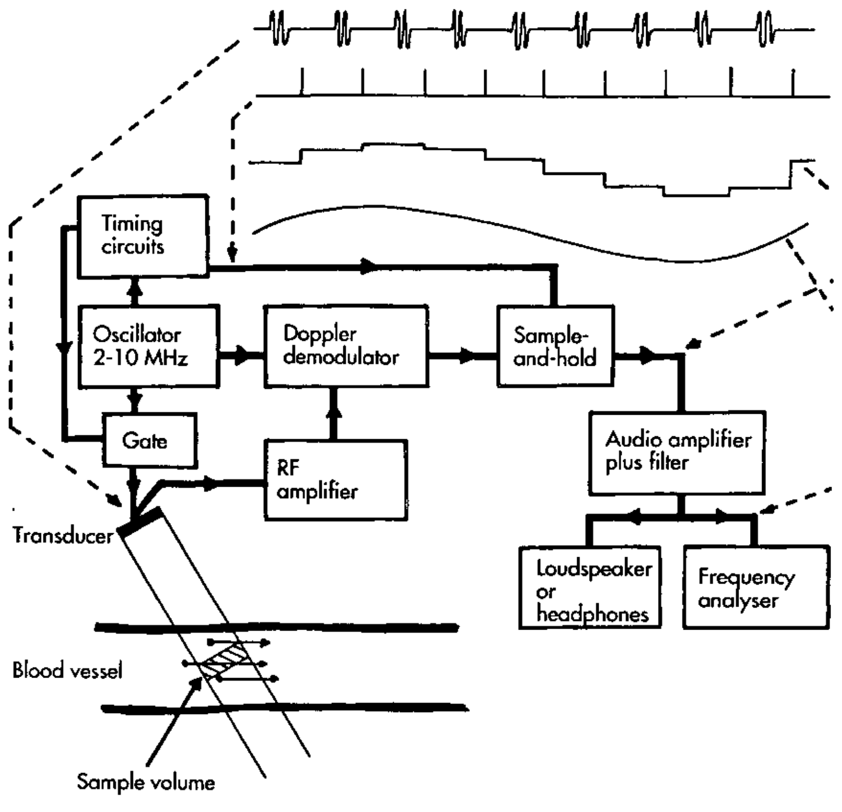

Fig. 7. Pulsed Doppler instrument

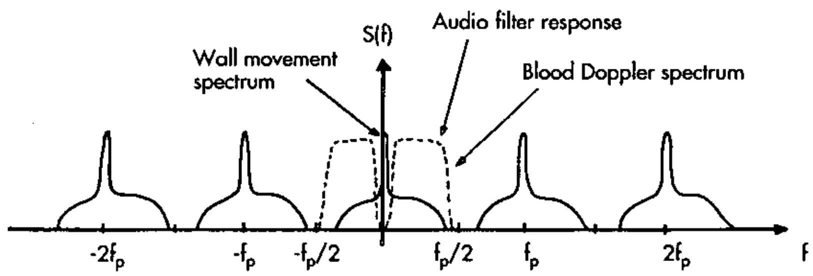

Fig. 8. Spectrum at demodulator output and audio filter response

Pulsed Doppler Instrument

A major limitation of the continuous wave instrument is that it is sensitive to flow in the whole region of overlap of the two ultrasound beams. This means that there is no separation of signals from two or more vessels in the beam and there is no separation of signals from different points in a single vessel within the beam. To overcome this problem we need an instrument with range resolution and this is provided by the pulsed Doppler instrument. A block diagram of the instrument is shown in Figure 7. Range resolution is achieved by periodically transmitting a short burst (a few cycles) of ultrasound (the burst or pulse repetition rate is set by the timing circuits, and the gate is opened for the duration of the burst), rather than transmitting continuously, and sampling or sampling and holding the output of the Doppler demodulator after a delay following each pulse transmission. The instrument is sensitive to flow only within a small sample volume (sv) at such a distance from the transducer that the transit time of the ultrasound pulse to the sample volume and back is equal to the delay between transmission and receiver sampling. The low-pass filter following the multiplier in the Doppler demodulator has a time constant usually comparable with the transmitted pulsed duration, and the pulse duration and this time constant determine the sample volume length. Its width is determined by the ultrasound beam. Since the functions of transmission and reception are separated in time a single transducer may be used as shown. The sample volume can be moved to different positions along the beam simply by altering the delay between transmission and demodulator sampling, and the instrument can therefore be used to monitor selectively, flow in vessels at different depths or at different positions within a single vessel.

As in the continuous wave Doppler instrument the signal from the demodulator is amplified and filtered and passed to loudspeaker (or headphones)

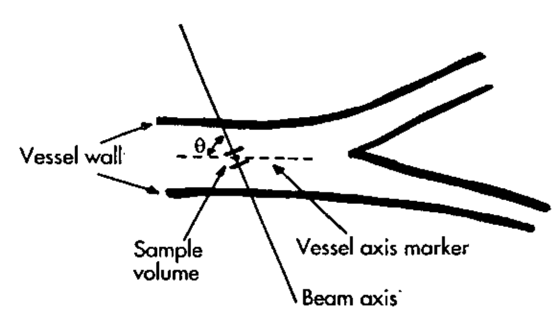

Fig. 9. Duplex scanner image

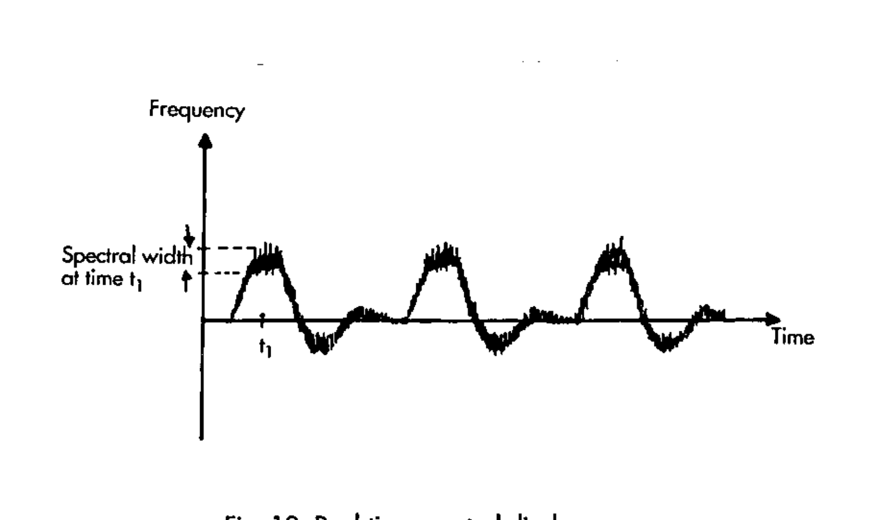

Fig. 10. Real-time spectral display

and frequency analyser. In the case of a pulsed Doppler instrument the high-pass filtration of the signal from the Doppler demodulator is determined by the pulse repetition frequency of the instrument. Since the instrument essentially samples the Doppler signal from the sample volume, the spectrum of the signal from the Doppler demodulator consists of the required signal spectrum together with copies occurring at multiples of the pulse repetition frequency (Figure 8). It is necessary to set this filter's cut-off frequency such that frequency components greater than half the pulse repetition frequency are strongly attenuated. The maximum Doppler shift frequency is therefore limited to half the pulse repetition frequency. As in the continuous wave instrument a flow direction discrimination can be achieved by using an offset frequency reference or by the use of two reference signals with a 90° phase difference.

Duplex Instruments

The pulsed Doppler instrument is often coupled to a real-time ultrasonic B-scan imager, allowing positioning of the sample volume at selected sites within imaged blood vessels. This combination is known as a Duplex scanner. The same or separate transducers may be used for imaging and pulsed Doppler measurements. In addition to enabling the operator to monitor flow at specific sites in imaged blood vessels (Figure 9), the instrument also enables a measurement of the angle between the blood vessel and the ultrasound beam to be made, thereby allowing a conversion from measured Doppler shift frequencies to velocities. Duplex instruments usually have a means of measuring this angle semi-automatically - an electronically generated marker line at the position of the sample volume may be rotated by the operator until it is lined up with the axis of the blood vessel, in which case the instrument knows the relative orientations of blood vessel and ultrasound beam and can calculate the angle between them. In addition, flow may be measured by incorporating a measurement of a blood vessel cross-sectional area using the electronic calipers of the B-scan instrument. Usually measurements are made by measuring a diameter of the blood vessel and assuming a circular cross-section.

Frequency Measurement

Early Doppler instruments used to measure Doppler shift frequencies by simply measuring the zero-crossing rate of the Doppler signal. It is usual nowadays to display the whole frequency content of the signal using a real-time spectrum analyser. The type of display is shown in Figure 10. The brightness of the display at any time and frequency indicates the power of the Doppler signal component at that particular frequency and time. The variation of Doppler spectrum width throughout each cardiac cycle may be monitored by this means and the maximum velocity waveform can easily be measured from the outline of the real-time spectral display.

Colour Flow Instruments

One of the limitations of pulsed Doppler instruments is that the information gained is relevant to only one small area in the scan-plane. Colour flow imagers seek to alleviate this problem by indicating in colour, information on

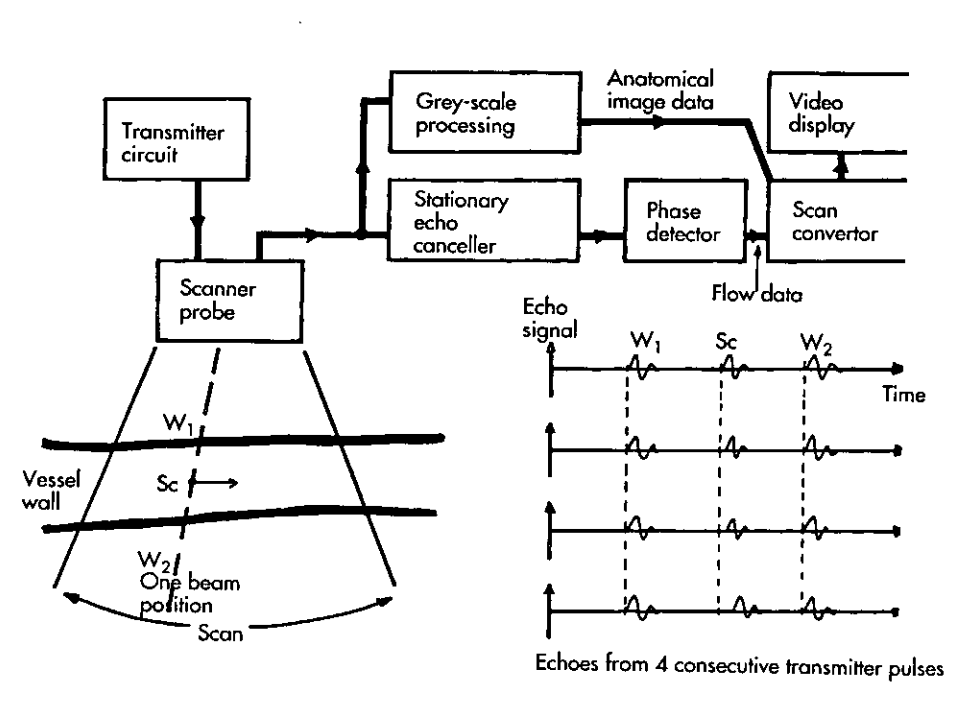

Fig. 11. Colour flow scanner

blood velocity superimposed on a normal grey scale image. The most usual method of achieving this is illustrated in Figure 11. At each beam position a number of ultrasound pulses are transmitted and the signals arising from stationary or slowly moving structures are eliminated by comparing the signals received after each transmitted pulse and eliminating those signals which are unchanged from pulse to pulse. The signals received from moving reflectors and scatterers are shifted in time (and therefore in phase) with respect to each other, as illustrated. The rate of change of phase (that is $2\pi \times f_d$) may be measured, the magnitude of the Doppler shift calculated and used to colour-code the display. By detecting the direction of phase shift, the direction of flow may be determined.

The mapping of Doppler frequency to colour may take a number of different forms. One arrangement is to display flow in one direction in red, the opposite direction in blue and to alter the colour saturation such that the colour changes from deep red (or blue) to white as the Doppler frequency increases. In order to reliably measure the Doppler shift frequency a number of pulses (typically 10) are transmitted along each beam position. Flow disturbance may be measured by measuring the variance of the phase shift between consecutive received pulses. This variance is small in the case of streamlined flow and increases in the case of disturbed flow. Disturbed flow may be displayed using a 'variance map' facility which indicates only disturbed flow. This may be combined with the display of streamline flow, making use of a third colour. Alternatively, disturbed flow may be indicated by a mosaic pattern of red and blue showing a mixture of flow directions within the disturbed-flow region.

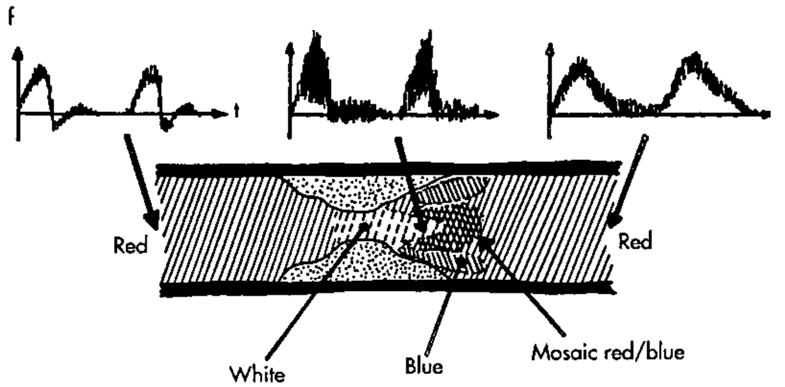

Fig. 12. Colour flow image of vessel in Figure 1 with pulsed Doppler real-time spectra

Display

The colour flow image and typical spectral displays from a diseased section of artery are shown in Figure 12. Note the increased maximum Doppler shift frequency within the jet from a stenosis, retrograde flow outside the jet, the increased spectral width due to flow disturbance and the dampening of the oscillatory maximum velocity waveform.

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Note from the Bulletin Editor.

The Editorial Board would like to include in future Bulletins, as part of an occasional series, articles on the techniques and application of acoustics from the past. For example in the issue of July 1990 we reproduced an article from *Vauxhall Engineering Leadership* of 1938 which described the measurement of internal vehicle noise and the means adopted to reduce it. With the photographs illustrating the heavy and cumbersome valve-based equipment used, the article aroused much interest among readers.

Mr Ralph Weston of the Royal Air Force Institute of Health and Medical Training has kindly offered us a wartime article from the forties dealing with measurements of the effect of aircraft noise on aircrew members and this will appear in the Bulletin in the near future.

If any members have access to similar historic articles or are prepared to write a piece on acoustics from the past (for example I have been told there is an interesting account waiting to be written of the earliest attempts made at the acoustic location of submarines that would make today's GCSE physics students smile) would they please contact me.

John Tyler

ULTRASOUND SURGERY

Gail ter Haar

Introduction

The aim of medical diagnostic ultrasound is to interrogate tissues with an ultrasonic beam in order to gain sufficient information from the scattered energy to be able to image the structures that the beam has encountered in its passage through the tissue, while not causing any significant biological change within those tissues. Imaging applications of ultrasound commonly use very short pulses (2-10 µs) at a low repetition rate (≈15 kHz). Thus, while the peak pressure amplitudes in the pulse may be high (1-3 MPa), the time average of intensity is relatively low. A typical time averaged intensity for a commercial machine is of the order of 100 $mWcm^{-2}$. At this intensity, the temperature rise induced within the tissue is biologically insignificant.

Ultrasound may also be used therapeutically. In these applications, biological change is actively sought. In the case of physiotherapy, these changes should be beneficial in that they should stimulate the processes of tissue repair and should produce pain relief. In surgery, the requirement is for tissue destruction that gives a very precise boundary between damaged and undamaged cells, and also produces the minimum of blood loss. By increasing the intensity in an ultrasonic beam, the required biological effect can be achieved.

There are two main ways in which ultrasound is used in surgery. One uses the potential of a highly focused beam to produce highly localised cell killing (focused beam surgery), and the other uses mechanical vibrations at ultrasonic frequencies to drive a knife blade, saw, metal tip or other instrument (tool surgery). This review will concentrate its attention mainly on the rapidly developing field of focused beam surgery.

Ultrasound Tool Surgery

Ultrasonic tools are comprised of a half wavelength piezo electric or magnetostrictive rod that is driven at an ultrasonic frequency, and is coupled by means of a waveguide to a suitably shaped cutting blade or tip. Frequencies up to 30 kHz are generally used, and the vibration amplitude of the working end is commonly 15-350 µm.

It has been shown that ultrasonically driven knives require less force to produce a cut than do conventional ones. This is due to the reduction in friction caused by having one vibrating surface [1]. In addition, the heat that is generated at the tip of such a scalpel blade may cauterize small vessels [2]. This clearly facilitates surgery as there is less bleeding in the area. Cryosurgical techniques may also be used to cut with reduced bleeding, but ultrasound has an advantage in that the tip does not stick to the tissues. Some surgeons prefer ultrasonic scalpel techniques to laser surgery because of the tactile feedback they obtain [3].

If the working end of an ultrasonically driven instrument is in the form of a sharpened hollow tube, then simultaneous cutting and tissue aspiration may be achieved. This is used for cataract removal in the eye [4]. Here, the lens is disrupted by the vibrating tip, and the fragments are sucked up through the tube.

Ultrasonically driven scalpels have been used successfully in highly vascularised organs such as the liver and spleen, and also for tracheotomies, tonsillectomies, and in the lungs, bronchial tubes, thoracic walls and eye [1, 2, 3]. An ultrasonic saw has been used to cut bone. In some hands, it is thought to be better for performing accurate osteotomies than conventional techniques [5].

The literature concerning ultrasonically driven surgical tools is largely anecdotal, but there are indications that some considerable benefits are to be had. It awaits some good engineering and basic science to put it on a firmer footing. Currently, aspirators are the most commonly used devices.

Focused Beam Surgery

Focused beam surgery makes use of the fact that the wavelength of sound in human soft tissues at the frequencies used for medical ultrasound (0.5 -10 MHz) is of millimetre dimensions (3.0 - 0.15 mm). This means that it can be brought to a tight focus at depth within the body. Judicious choice of the focal gain means that whereas total tissue destruction may be achieved within the focal volume, the energy density elsewhere can be sufficiently low so as not to damage cells. The principle is demonstrated in Figure 1. The damaged volume is known as the focal lesion. It is ellipsoidal in shape, reflecting the intensity distribution at the beam focus. Figure 2 shows a lesion made in liver at a frequency of 1. 7 MHz. The ultrasonic beam entered through the liver capsule, the focus was positioned 4 cm below this surface.

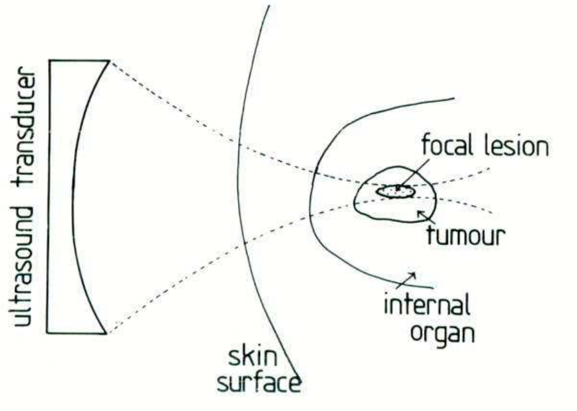

Fig. 1. Schematic diagram showing the principle of focused ultrasound surgery. The source is situated outside the body, and the energy is concentrated within internal organs.

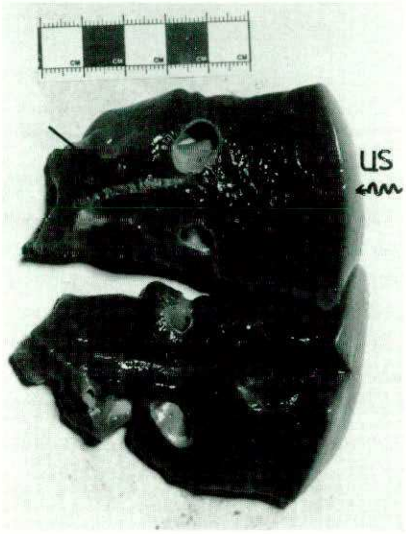

Fig. 2. Ultrasonic lesion (arrowed) produced in a piece of butcher's liver. The direction of the incident ultrasound beam is shown.

Ultrasound was first focused by Greutzmacher [6]. The first biological applications of focused beams were attempts by Lynn and colleagues to put lesions into cat brain [7, 8]. This work initiated interest in neurological applications of ultrasound surgery [9, 10, 11, 12, 13, 14, 15]. Studies include its use as a research tool in the investigation of nerve conduction [16] and behaviour [17], but there has been very little clinical use. Human applications include experimental treatment of Parkinson's disease [18] and treatment for pain relief of subcutaneous neuromata [19].

There has also been considerable interest in other fields of medicine. It is in ophthalmology that focused beam ultrasound has, to date, found its most widespread use, for the treatment of glaucoma.

The earliest study of the effects of focused ultrasound in the eye was conducted by Lavine and colleagues [20]. This team observed that focused ultrasonic energy could cause cataracts. More recently, most of the research into this field has been carried out in New York. The team here has shown that it is possible to 'fuse' the choroid and retina using very small lesions [21]. The small lesions (0. 4 mm diameter, 4 mm long) were obtained by driving the transducer at its seventh harmonic in order to get a sufficiently high frequency (9. 8 MHz). This group has done extensive mathematical modelling in an effort to be able to predict lesion behaviour under any given clinical situation [22, 23].

It has been shown that high intensity focused ultrasound can successfully reduce intra-ocular pressure in glaucoma [24]. Average intensities up to 2000 Wcm^{-2} at a frequency of 4.6 MHz were used.

There has been a resurgence of interest in the use of focused ultrasound surgery for the treatment of human solid tumours. In principle, the technique allows the destruction of malignant tissue within a deep organ in the body without recourse to conventional surgery.

It has been shown that implanted tumours in experimental animals may be successfully treated with focused ultrasound [25, 27]. Published human clinical trials of the technique in oncology have been limited. A variety of tumour types were treated in the mid 1960's [28, 29]. Tumour regression with no increase in metastasis was observed.

An obvious application for high intensity focused ultrasound lies in the enlarged prostate in benign prostate hyperplasia (BPH). There is some evidence that heat killing of cells within the gland leads to its debulking [30]. If this is useful in relieving the symptoms of BPH, then focused beam surgery appears to be tailor-made for producing the thermal lesion.

Vallancien and his group, working in France, have modified a commercial lithotripter for use with highly focused ultrasound [31- 33]. They have initiated clinical trials, and have treated a number of different human cancers in the bladder, kidney and prostate. A second French group has modified a different lithotripter for similar use [34]. A transrectal device for the treatment of BPH using focused beams has been developed in the United States [35]. This device operates at 4 MHz.

Ultrasound transducers for focused beam surgery

Quartz transducers were used for the early research into focused ultrasound surgery [9, 13]. More recently, piezo electric ceramics have been used. A common material is the high power lead zirconate titanate, PZT5. For therapy applications of ultrasound, the transducer is air backed, often with a spring loaded point pressure contact to the back face.

Focusing may be achieved either by combining a plane transducer with a lens, as shown in Figure 3, or by suitably shaping the transducer element to produce focusing [36]. The source typically used by the team at the Royal Marsden Hospital is a 10 cm diameter focused bowl with a focal length of 15 cm. The beam plots obtained from such a transducer are shown in Figure 4.

Other devices have made use of multi-element transducers. For example, Vallancien et al have used 36 piezo-electric elements arranged as a hemispherical disc [37]. They, in common with the New York group [38]

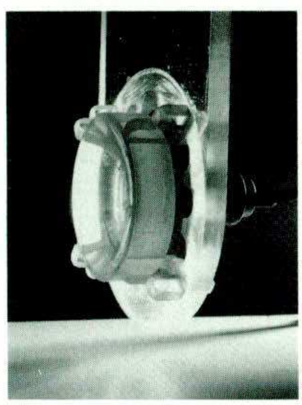

Fig. 3. Plane piezo-electric disc transducer with a bi-concave perspex lens used in focused beam ultrasound surgery.

have incorporated an imaging transducer into the lesioning head.

Mechanisms for tissue damage

The main way in which tissue destruction is obtained using this technique is by heating. Figure 5 shows the temperature rise measured at the focus of an ultrasonic field in a piece of unperfused butcher's liver. The temperature was measured using a fine wire (25 µm) copper-constantan thermocouple. It can be seen that there is a very rapid temperature increase up to about 90°C within the first 30 seconds. There is a well known relationship between the absolute temperature and the time for which it must pertain, in order to produce known biological effects. Cell killing is achieved in less than 5 seconds for temperatures above 60°C.

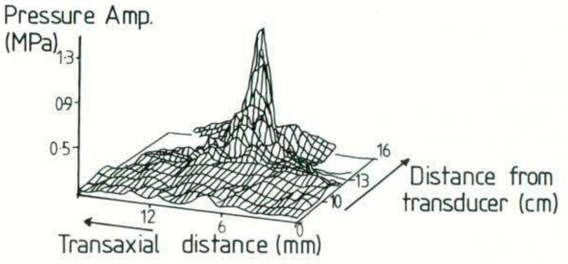

Fig. 4. Acoustic field distribution from a focused bowl ceramic transducer obtained using a PVDF membrane hydrophone. This transducer had a focal length of 15 cm, a 6 dB pressure width 2.1 mm across the beam axis, and 2.1 mm along the beam axis.

The other mechanism for cell destruction is acoustic cavitation [39]. Histology of focal lesions made in liver, reveals holes or 'implosion cysts' [40]. These may be due to collapse cavitation, or to vaporization from the high temperatures achieved. It is probable that some of the damage seen in the focal region is due to cavitation, since the acoustic pressures used are above those normally regarded as 'threshold', especially at the elevated temperatures involved.

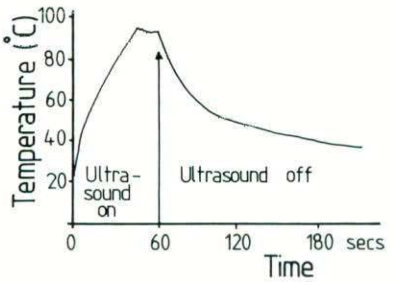

Fig. 5. Graph showing the temperature rise at the focus of an ultrasound beam in unperfused liver.

Ultrasonic Imaging

A unique feature of this form of tissue destruction is that the damage may be monitored non-invasively in real time as it is produced. Focal lesions show up as relatively echogenic regions on a diagnostic ultrasound image. Figure 6 shows an image of a lesion made in liver. The progression of tissue damage may be monitored using MRI (magnetic resonance imaging) techniques [40, 41]. When an intravenous contrast agent (GdTPA) is used, the boundaries of the lesioned volume are clearly visible on the MR image.

Summary

It is clear that there is renewed interest in clinical applications of focused ultrasound surgery. Much basic work at a biological level was carried out in the 1950's, but the advent of good diagnostic imaging techniques has meant that accurate placing of focal lesions within a desired tissue volume has become a viable proposition, and exciting clinical applications have become a realistic goal.

Whereas the biology has been pursued fairly vigorously over the years, there is now a need for physics and engineering expertise to aid in the development and optimisation of integrated therapy and diagnostic transducers, and in understanding and executing treatment planning.

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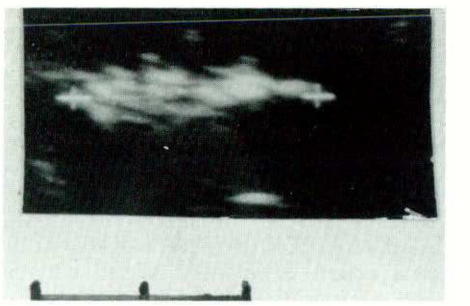

Fig. 6. Diagnostic ultrasound scan of a liver lesion. The damaged tissue shows up as an echogenic region on the image. The scale is marked in centimetres.

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ACOUSTIC DISINTEGRATION OF KIDNEY STONES

A J Coleman

Stone disease

Urinary stone disease is one of the oldest and most acutely painful diseases known to man. It is caused when the urine, for various reasons, becomes supersaturated with particular salts which may then crystallize out of solution forming a stone-like calculus. These stones, apart from causing intense pain, may ultimately induce renal failure through obstruction and infection of the urinary tract. The open surgical removal of urinary stones involves one of the longest and most painful incisions in surgery and alternative treatments have long been sought.

For most of its history urinary stone disease has been associated with the bladder. One famous sufferer, Samuel Pepys, had his stone surgically removed by Thomas Hollier of St Thomas' Hospital on the 26th of March 1658. The pre-anaesthetic surgical removal of bladder stones was fraught with risk and Pepys, grateful to survive, held a dinner for friends every year on the 26th of March as 'my solemn feast for the cutting of the stone'. Lithotomy, as this operation is termed, reached its peak of perfection in the work of William Cheselden (1688-1752) also of St Thomas' Hospital who could perform the operation in a matter of minutes. Dietary changes dating from the late 19th century appear to have resulted in a steady decrease in the occurrence of bladder stones so that they are now a rarity. Stone formation occurs most commonly nowadays in the upper urinary tract. It has a prevalence of 3.5-3.8% of the population in the UK and accounts for some 10,000 admissions to hospital per year.

A rather large partial 'staghorn' kidney stone which has been surgically removed is shown in Figure 1. Open surgery for removing kidney stones has within the last decade, been replaced by less invasive methods of which the acoustical technique known as extracorporeal shockwave lithotripsy (ESWL) is now dominant. This technique involves focusing high amplitude pulsed ultrasound onto the stone in order to cause fragmentation. Since the acoustic source is located outside the body the technique involves no surgical incision and stone fragments pass naturally down the urinary tract. Since their introduction in 1980 extracorporeal lithotripters have become widely available so that there is now a concentration of about one lithotripter per million people in Europe and the United States. About 85% of all cases of symptomatic kidney stones are now treated in this way. Along with percutaneous and endoscopic methods for extracting or crushing stones, ESWL has largely replaced the once dominant open surgical operation for kidney stone removal which is now performed in less than 1% of cases.

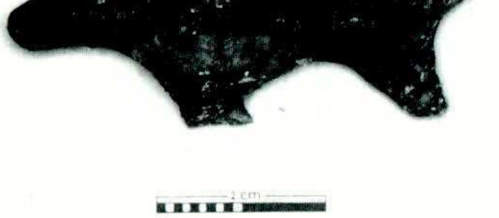

Fig. 1. A partial 'staghorn' stone which has been removed from the renal pelvis at open surgery.

Development of lithotripsy

Ultrasonic methods for fragmentation of stones were first seriously considered in the 1950s when Lamport and Newman [1] showed that a 400 kHz continuous wave directed from a distance at a gallstone suspended in water could shatter the stone. Various subsequent attempts at contact free ultrasonic stone fragmentation, also in vitro, proved less successful and research in this area ceased by the end of the decade, following publication of a paper which demonstrated dangerous (60° to 80° C) temperature rises in animal tissue resulting from exposures (of 5 mW/cm^2 at between 100 kHz and 1.5 MHz) sufficient to cause fragmentation.

With the development of minimally invasive percutaneous and endoscopic surgical techniques, interest in the ultrasonic methods revived in the 1960s since the source, if sufficiently small, could be relatively conveniently placed in close contact with the stone, eliminating the problems related to ultrasonic heating of intervening tissue. One of the first such clinical uses was carried out by Goldberg [2] in 1959 using an endoscopic procedure in which an electrohydraulic source was passed through the urethra and placed in contact with a bladder stone. The electrohydraulic source used in this procedure consisted of a coaxial cable in which the tip was bared to allow an electrical discharge between the central core and the earth screen. Pulsed and continuous wave ultrasonic transducers placed at the tips of flexible catheters are still used in percutaneous lithotripsy, alongside mechanical grabbing and crushing instruments and, more recently, laser lithotripters in which a pulsed laser beam passes down a fibre optic cable to the stone. While percutaneous techniques play an important role in the management of urinary stone disease, particularly where the stone is large (>1 cm diameter) or is in the lower urinary tract, they require the use of anaesthesia and are, by nature, invasive.

Hausler and Keifer [3] were the first to demonstrate the contact free acoustical fragmentation of stones in vitro. They used high amplitude shock waves generated by liquid droplet impact on the surface of a liquid in which the stone was submerged. By pulsing at a sufficiently low rate, problems related to heating of intervening tissue formerly associated with contact free lithotripsy, were eliminated. The successful development of contact free ultrasonic stone fragmentation, known as extracorporeal lithotripsy (ESWL), was carried out during the 1970s by the West German company Dornier GmbH. Following development of a convenient focused electrohydraulic source of high amplitude acoustic pulses, the treatment was clinically tested between 1980 and 1982 at the Department of Urology at the University of Munich under the direction of Christian Chaussy using the Dornier HM-I and HM-2 electrohydraulic lithotripters [4]. The first commercial extracorporeal lithotripter (Dornier HM-3) became available in 1982.

There are now more than seven manufacturers of clinical lithotripters including Dornier (Germany), Siemens (Germany), Wolf (Germany), Storz (Switzerland), EDAP (France), Technomed (France) and Medstone (USA). The absence of a UK manufacturer follows the trend for much hi-tech medical equipment. Machines cost between £250,000 to £750,000 and the market for lithotripters in the treatment of urinary stone disease is generally considered to be nearly saturated, with companies competing largely for the replacement market. Manufacturers' hopes that lithotripters might be used in gallstone treatment have not proved well-founded. Although these stones are ten times more common than urinary stones, the surgical operation known as cholesystectomy, which involves the removal of the entire gall bladder and contents, can now be performed using new minimally invasive surgical techniques and use of ESWL is thus limited to the 20% of cases where the stone is inaccessible to surgery or when the patient is unwilling or unsuitable to receive a general anaesthetic.

Entracorporeal Lithotripsy

A Storz Modulith SL10 entracorporeal lithotripter was installed at St Thomas' Hospital Lithotripsy Centre in 1990. This lithotripter uses an under-couch electromagnetic acoustic shockwave source with a water inflatable membrane to couple the shock waves into the patient. The large water filled membrane can just be seen directly below the patient in Figure 2. The patient lies supine or prone (depending on the location of the stone) and the stone is localized at the shock wave focus using in-line and hand held 3.5 MHz ultrasound sector scanning probes. Part of the ultrasound imaging system is seen to the left of the operator in Figure 2. Not shown in this figure is the X-ray imaging system which can also be used for localizing the stone at the shockwave focus.

The geometry of the acoustic source used in the Storz Modulith is shown in Figure 3. The shock wave is generated by a cylindrical metallic membrane of about 9 cm diameter and 12 cm length which is induced to flex when a coil, around which the membrane is wrapped, is energized by a high voltage capacitor discharge. The cylindrical wave emitted by the metallic membrane is focused using a solid brass parabolic reflector of about 30 cm aperture diameter. The wave propagates in degassed water and is transmitted through the flexible plastic membrane. The focal position is about 17 cm in front of the aperture.

The pressure waveform generated by this acoustic source at the position of the beam focus is shown in Figure 4. This waveform has been measured using a PVdF membrane hydrophone. As is typical of most lithotripsy fields [5] the leading edge of the pressure waveform is relatively steep compared with the trailing edge and the wave is said to be shocked. Also worthy of note is the negative pressure excursion which is typically of sufficient amplitude to cause acoustic cavitation in ordinary distilled water and, almost certainly, also in tissue. Peak positive pressures of between 40 and 120 MPa and negative pressures of up to 9 MPa are recorded at the beam focus in water depending on the source output setting. The Fourier representation of this waveform shows a range of frequencies. The fundamental frequency is around 200 kHz which is low by the standards of most medical ultrasound equipment (1-5 MHz). However, the pulse also contains frequencies beyond 10 MHz. As far as the efficiency of stone fragmentation is concerned, the high frequencies appear to play no significant role, and are likely to be heavily attenuated following propagation through the intervening 6 cm of tissue.

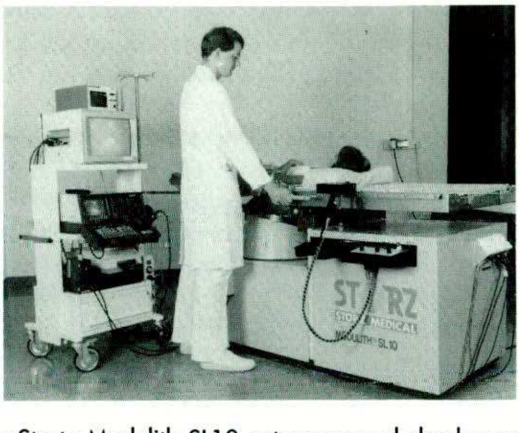

Fig. 2. The Stortz Modulith SL10 extracorporeal shockwave lithotripter. The focused acoustic source fires upwards from below the patient and the beam is coupled to the patient by a flexible water filled membrane.

Treatment

The main criteria used for selecting patients for ESWL are that the kidney stone is symptomatic or rapidly enlarging. Large stones that have arms which extend into the calyces of the kidney, known as staghorn calculi, are not treated as a primary procedure since experience has shown that these are best treated by debulking either by open or percutaneous surgery before lithotripsy. This technique reduces the risk of stone fragments blocking the ureter. Stones in

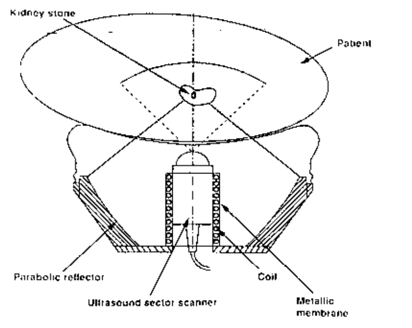

Fig. 3. A diagram of the acoustic shockwave source used in the Stortz Modulith. A cylindrical coil is energized and induces an adjacent metallic membrane to flex. The cylindrical diverging wave is focused by a reflector onto the kidney stone which is localized at the beam focus using an in-line ultrasound scanner.

the ureter above the iliac crest can be treated in situ but those below have to be pushed back into the renal pelvis, where the stones can be more easily imaged before ESWL. The surgeons have dubbed this the 'push bang' technique since most acoustic sources in lithotripsy generate an audible noise (or bang) when fired.

There are several contra-indications for lithotripsy as for most procedures. Large patients are often difficult to treat because the stone is difficult to visualize for location at the shockwave focus. Pregnancy is taken as an absolute contra-indication because of possible damage to the foetus and certain cardiac pacemakers may be affected by the electromagnetic pulse which accompanies the acoustic pulse.

Treatment itself takes less than one hour, during which the patient is placed on the couch and the stone localized at the shockwave focus using the appropriate imaging system. An average of 1500 (maximum of 2500) shockwaves are administered to each stone. The degree of stone disintegration can be monitored to some extent on the X-ray or ultrasound image. In the early lithotripters it was necessary to use a general anaesthetic. By increasing the focusing gain of the acoustic source it was found that pain associated with sensation at the skin could be eliminated. Local anaesthetics may still be used along with mild sedation to assist the nervous patient and reduce movement during treatment.

The immediate after-effects of treatment by ESWL include haematuria resulting from bleeding in the kidney tissue caused by the shockwave passage. Some minor skin bruising is also often observed at the entry and exit areas of the shockwave. These symptoms normally resolve within a few days. Studies into possible damage to tissue have identified morphological changes in kidneys following ESWL, diminished perfusion, perirenal fluid collection and oedema. As yet there is no evidence of suggested long term effects such as a reduction in renal function or an increased incidence of hypertension.

A straightforward case has an in-patient stay of two or three days. The patient requires X-ray and ultrasound before treatment to assess suitability of the stone before ESWL. Post treatment the patient is closely followed up to assess urinary output and to examine evidence of infected renal obstruction which, if present, requires immediate treatment. Further X-rays or ultrasound imaging is carried out to monitor the passage of stone debris. Apart from the short hospital stay, a significant economic advantage of ESWL treatment over other techniques is that the patient can resume his or her normal occupation immediately; convalescence from open surgery may take several weeks.

While the treatment for gallstones is similar, the removal of debris from the gall bladder is a considerable problem, since the bile is far more viscous than urine and the gallbladder is less efficiently flushed than the kidney. Drugs have to be given for a long period before and after treatment to dissolve the fragments left after lithotripsy. Modern techniques of minimally invasive surgery which remove the entire gallbladder are often preferable since they also remove the otherwise high incidence of gallstone stone recurrence.

Stone fragmentation

It is apparent from several studies that stone fragility during lithotripsy depends to a greater or lesser extent on the chemical composition, the crystalline structure, flaw size and distribution, microhardness and elasticity, stone volume and shape as well as gas content, amongst other factors. It is also clear from both *in vitro* and *in vivo* studies that the number of stones and the properties of the fluid surrounding the stone critically influence the degree of fragmentation.

Much of the information on the mechanisms of stone fragmentation have come from studies using stone substitute materials including calcium sulphate and glass marbles, breeze blocks, plaster balls, Z-Bricks, fire bricks, chalk cubes, Plaster of Paris and synthetic stones. These studies identify differences between so-called 'direct' effects resulting from propagation of the shock in the stone material and 'indirect' effects which appear to be mediated by the fluid surrounding the stone. Direct effects are attributed to spalling, in which high tensile stresses appear in the stone as a result of internal reflection of the shockwave, and indirect effects attributed to acoustic cavitation. Estimates have been made of the magnitude of other indirect effects including acoustic streaming in ESWL but these have not been examined experimentally.

Indirect effects can be inhibited by immersing the stone substitute in a viscous medium such as PVA gel or glycerol and this generally reduces stone substitute damage. Such damage inhibition is generally attributed to the reduced cavitational activity resulting from the viscosity increase although it should be noted that the relative importance of direct and indirect effects appears to alter with other factors including stone size and hardness, with larger and harder stones being more susceptible to spalling damage.

Research areas

In the decade that commercial lithotripters have been available there have been many studies into the biological effects of the acoustic fields they generate, which are reviewed by Brummer et al [6]. The acoustic pulse with its long, high amplitude, negative pressure excursion is a potent generator of transient cavitation and the studies of tissue and cell damage both *in vivo* and *in vitro* confirm that cavitation plays a dominant role. In particular, the appearance of lesions induced by lithotripsy exposure in soft tissue are quite different from those generated by continuous wave focused ultrasound. These latter lesions occur in a well-defined region at the beam focus and are attributed mainly to thermal effects. Lithotripsy exposures, in contrast, generate small haemorrhages which appear scattered over a relatively wide region and occur preferentially close to blood vessels.

Transient cavitation is an phenomenon of considerable interest in the study of the safety of medical ultrasound particularly at diagnostic levels. Little is known about the number or distribution of gas bubbles in mammalian tissue and, while no adverse effect has been observed at clinical diagnostic levels, the theoretical possibility that the short pulses used in imaging techniques may excite any pre-existing bubbles into some violent oscillation makes it important to examine these effects. As potent generators of transient cavitation, lithotripsy fields may be expected to provide information on the bubble distribution in tissue [7].

Possible therapeutic applications of focused shockwave fields beyond lithotripsy have also been studied. As a primary treatment for tumours these fields appear to offer little advantage over other techniques. Tumour tissue, which is often poorly vascularized, suffers less damage than well perfused healthy tissue. Indeed some studies show that tumour growth can be better inhibited by exposing the surrounding healthy tissue than the tumour tissue itself. Any reduction in tumour growth that can be achieved by exposure to lithotripsy fields is temporary. This lack of effect has led to the search for possible synergistic effects in which vascular damage from lithotripsy exposures can be employed to enhance other treatments including, for example hyperthermia treatment of tumours. These lines of research appear to offer only a limited role for acoustic shockwaves in cancer therapy.

Studies with cells in suspension have demonstrated that lithotripsy fields, in common with many lower level ultrasonic fields which generate cavitation, are capable of disrupting cells. A proportion of the cells which remain intact appear in addition to have damage to their outer membrane so that they appear to be more permeable to certain drugs. As a therapeutic technique for enhancing drug uptake in, for example tumours, lithotripsy offers little advantage over lower level ultrasonic fields which can also produce this effect without the accompanying tissue damage.

There has been some recent interest in the possible enhancement of bone growth from exposure to lithotripsy fields. The current understanding of the mechanism of this effect is that the shockwave causes microfractures in bone which then encourages the growth of vessels and hence bone growth. Osteogenesis, as it is called, would be of use in the treatment of certain conditions where bone healing is slow. As yet such a technique remains to be proven.

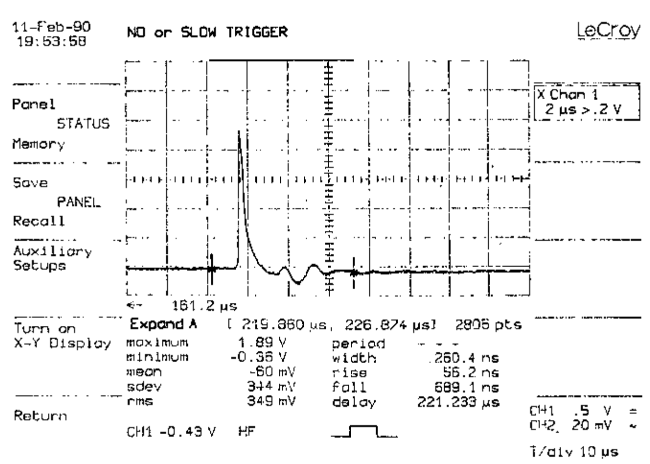

Fig. 4. The pressure waveform measured at the beam focus in water of the Storz Modulith using a PVdF hydrophone. The peak positive pressure exceeds 50MPa. Pulses are fired at a frequency of around 1 Hz, and about 2000 are required to disintegrate most stones.

Conclusion

Extracorporeal shockwave lithotripsy provides a remarkable example of the use of sound in medicine. The technology has been rapidly accepted by surgeons and ESWL has become the treatment of choice for kidney stones. Further therapeutic uses of these fields appears at present to be limited to those areas where their superior ability to generate cavitation may be important, as in disruption of tissue vasculature and the induction of microfractures in bone. Closer study of cell and tissue damage resulting from these cavitating fields may be expected to improve our knowledge of transient cavitation in human tissue and the safety of medical ultrasound in general.

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Wednesday19 May 1993

In Section 73 of the Control of Pollution Act 1974, it is stated that noise includes vibration.

Only in the past few years, though, has our understanding of the effects of vibration and our ability to measure it with relative ease enabled the subject to be addressed in a similar manner to noise.

Whether the source of vibration is transportation or construction works, and whether the effects are on people, buildings or the equipment within buildings, the importance of vibration cannot be under-estimated by developers, planners or regulators.

This one day meeting provides an opportunity to present papers on any aspect of environmental vibration including:

Standards / criteria;

Prediction methods;

Mitigation techniques;

Instrumentation;

Case studies

Abstracts of no more that 200 words in length are invited for any of the above topics or other issues relating to environmental vibration. Abstracts should arrive by 31 December 1992. Notification of acceptance will be given by 31 January 1993.

Full papers, which will be published in the Proceedings of the Institute of Acoustics, Volume 15 (1993) will be required for printing by 31 March 1993. Camera ready paper based on a normal length of 8 pages will be supplied, along with word - processor formatting instructions.

Abstracts should be sent to:

S W Turner MIOA Rendel Science & Environment, 30 Great Guildford Street London SEl OES Tel: +44 (0)71 962 9884 Fax: +44 (0)71 962 9885 879

Workshop

Background Noise Measurement in Planning and Nuisance

South Bank University, London

Monday 5 April 1993

There will be four invited contributions and the rest of the day will be taken up with a workshop discussion. It is intended that current and future legislation will be examined regarding the instrumental and procedural difficulties encountered when making reliable background noise level determinations in the real world.

Further information may be obtained from John Seller MIOA at the Institute of Environmental Engineering, South Bank University, Borough Road, London SE1 0AA. Tel: 071 928 8989, Fax: 071 928 2306 or from the IOA office.

MEETING NOTICE

Acoustical measurements and NAMAS accreditation

National Physical Laboratory, Teddington

Thursday 11 February 1993

Issues of quality assurance, traceability and accreditation are growing in importance in the field of acoustics. This meeting has been planned to include guidance and advice on preparing for NAMAS accreditation, experiences of laboratories involved in instrument calibration and in acoustical testing, aspects of current sound level meter standards and related, and sometimes controversial issues, such as the traceability requirements in BS 4142: 1990. The meeting will also provide an opportunity to discuss future growth areas in acoustical testing, possibly requiring new calibration services for traceability.

Provisional Programme

The process of accreditation
Yuk Y Cheung, NAMAS

Sound level meter calibration and verification
Susan Dowson, NPL

Accreditation: the NAMAS viewpoint
Martin Shipton, NAMAS

NAMAS acoustical calibration: the human factor
Glynne Parry, Lucas CEL Instruments Ltd

Type approval and official calibration of sound level meters in Germany
Ian Campbell, Lucas CEL Instruments Ltd

The role of computers and software
Dudley Wallis, Cirrus Research plc

An acoustic consultant's view
David Fleming, Fleming and Barron

Living with NAMAS: the view of an accredited testing laboratory
Tony Jones, AIRO Ltd

In addition to the presentations, we plan to have a discussion period in a small group/workshop format.

Meeting Organisers:

Bernard Berry and Peter Hanes
Acoustics Branch Division of Radiation Science and Acoustics
National Physical Laboratory
Teddington TW11 0LW
Tel: 081 943 6316/6215 Fax: 081 943 6161

Please register me as a delegate to the NAMAS meeting at NPL
Name:
Organisation:
Address:

Tel: Fax:

Please invoice me for the meeting fee of

☐ £75 + £13.13 VAT = £ 88.13 (members)

☐ £90 + £15.75 VAT = £105.75 (non-members). The fee covers lunch and the meeting handbook.

☐ I cannot attend, please send me a copy of the proceedings. A cheque for ☐ £18 (members) or ☐ £25 (non-members) is enclosed.

Institute of Acoustics, PO Box 320, St Albans, Herts AL1 1PZ. Tel: 0727 48195, Fax: 0727 50553.

MEETING NOTICE

External Vehicle Noise and Impending Legislation

Church House Conference Centre, Westminster, London

Thursday 4 March 1993

Meeting Organisers
David Bull, Colchester Institute; David Balcombe, Lotus Engineering; John Tyler, TRL.

There is currently a proposal before EC that drive by noise be reduced to 74 dB(A) for cars and light trucks by October 1994. Also there is a standard road surface that has been established by ISO which will have to be used for all future type approval testing. This meeting will be of interest to vehicle manufacturers, tyre and exhaust companies, research organisations, consultants and environmentalists generally.

Programme

The meeting will be opened at 10 am, following registration and coffee at 9.30 am, by
Mr Eric Dunn, Chief Mechanical Engineer, Department of Transport

Vehicle noise legislation - an overview
J M Dunne, Vehicle Standards Division, Department of Transport

The challenge to identify external vehicle noise
M Armstrong, Bruel & Kjær (UK)

Noise prediction - what some computer models can do
C F McCulloch, Dynamic Engineering

Vehicle noise legislation - a truck industry viewpoint
D Nash, Foden Trucks

Tyre noise testing
P Nelson & S Phillips, TRL

Practical development problems in achieving 74 dB(A) for cars
D R Balcombe & P Crowther, Lotus Engineering

Intake and exhaust modelling
M Harrison, Lotus Engineering

Noise emission levels from passenger cars - past, present, future
T Berge, Sintef Delab, Acoustics Research Centre, Norway

Effect of ISO surfaces on pass-by noise levels
A Walker, MIRA

Please register me as a delegate to External Vehicle Noise
Name:
Organisation:
Address:

Tel: Fax:
Please invoice me for the meeting fee of
☐ £75 + £13.13 VAT = £ 88.13 (members)
☐ £90 + £15.75 VAT = £105.75 (non-members). The fee covers lunch and the meeting handbook.
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Institute of Acoustics, PO Box 320, St Albans, Herts AL1 1PZ. Tel: 0727 48195, Fax: 0727 50553.

MEMBERSHIP

The following were elected to the grades shown at the Council Meeting held on 8 October 1992.

Fellow
Feuillade, C
Orlowski, R J
Rindel, J H
Walker, R

Member
Allish, P J
Bichard, E M
Chan, K K
Chapman, I D
Clampton, S J
Fung, W S W
Gallop, R J
Hamson, K G
Hargreaves, N M
Hernaman, R E
Hussain, M
Ip, T Y
Jones, A R
Lednik, D
Lester, H
Manvell, D
Michel, P G
Mosley, D W
Ng, C F
Reddy, N N
Robinson, C
Rochester, B
Sams, I J
Stephens, P W
Sullivan, K P H
Watson, A B
Woodward, P

Associate Member
Aghomi, J
Baldock, A P
Baxendale, D J
Belton, C R
Blyth, D R
Boucher, G R
Bowdler, L C
Bradley, D M
Braithwaite, R D
Brook, H
Choi, S M
Castle, L
Cawley, J K C
Crease, A W
Cunion, D C
Delaney, S P
Dorling, G R
Durell, P J
Dutton, A J
Ellis, D
Ennis, A D
Frost, C
Gibbs, J L
Gillott, J A
Gong, K W C
Gorvin, D P
Harbach, K
Harris, B G
Heffernan, C B
Holmes, R
Howliston, D
Hughes, P R
Jackson, K
Jones, D L
Langrick, S A
Lepki, S A
Lewis, A
Liu, W L R
Long, M C
Marchant, I J
May, A
McGloin, I
Megainey, C G
Muir, R F
Natton, A J
Newman, P A
Obermayer, P
Orton, T M
Phillips, I M
Poole, B C
Poole, G S R
Redknap, J E
Sawyer, K V
Shad, N A
Shaw, K
Simmonds, C V
Smith, J R C
Summers, T J
Walton, M T
Weston, S A
Whitehead, D
Williams, B L
Woollaston, H
Woolley, R J
Wright Reid, A
Young, B J

Associate
Aduaka, C J
Hern, P
Smith, A G
Tam, W A

Student
Bangash, M A
Treby, N D

INSTITUTE MEETINGS & CONFERENCES

1993
11 February
'Acoustical Measurements and NAMAS Accreditation, Calibration and Testing', National Physical Laboratory, Teddington.*

4 March
Industrial Noise Group
'External Vehicle Noise and Impending Legislation', Church House Conference Centre, London.*

5 April
'Background Noise Measurement in Planning and Nuisance', - Workshop Meeting - South Bank University, London.*

14 - 16 April
Underwater Acoustics Group
'Acoustic Classification and Mapping of the Sea Bed',
University of Bath.

20-23 April
Acoustics '93
1993 Institute Spring Conference in collaboration with SFA.
University of Southampton.*

19 May
London Branch, 'Environmental Vibration', Regents College, London.

June
Building Acoustics Group
'Building Services Noise', London venue.

September
'Noise and Vibration from Underground Transport', London venue.*

28 - 31 October
'Reproduced Sound 9',
Hydro Hotel, Windermere.*

18 - 21 November
1993 Autumn Conference
'Environmental Noise',
Hydro Hotel, Windermere.*

December
Underwater Acoustics Group
'Short Range Propagation Communication and Telemetry',
University of Birmingham.

1994
18-21 April
Acoustics '94
1994 Institute Spring Conference
University of Salford.*

* *IOA Meetings Committee programme.*

ACOUSTICS AND SOUND CONTROL IN UCI MULTIPLEX CINEMA DESIGN

Vernon Cole MIOA

Introduction

People are going to the pictures again. Since the mid eighties, cinema attendance in the UK has increased by over 100%, and an industry which ten years ago seemed to be in terminal decline has experienced a major resurgence. Much of this can be attributed to the arrival of the multiplex.

A multiplex is a cinema venue with a number of screens. The choice of viewing is a major draw for the type of customer whose preference is an evening out at the cinema rather than the wish to see a specific film. And these days, an evening out at the cinema offers an experience unlike anything that can be achieved through the TV and video medium at home.

A modern multiplex is equipped with technically advanced projection equipment and sound systems, together offering high quality audio visual entertainment. Seats are comfortable, sight lines are good, and with modern well designed foyers, a wide range of refreshment choices and customer orientated staff, it's all a far cry from the 'flea pits' of old.

UCI

United Cinemas International opened the first UK multiplex in 1985. Since then, it has gone on to open well over two dozen more with several under development. Similar facilities in Ireland, Germany and Spain have now made it a major European exhibitor.

The number of screens in a UCI multiplex ranges from 6 to 18 and the size of the auditoria from 170 to 550 seats. They can be located in shopping centres or leisure complexes and spread over one level or split between several. Nevertheless, while these basic characteristics may vary, UCI multiplexes are built to a formula which ensures a degree of conformity. The formula demands a generic cinema layout which facilitates patron circulation and can be constructed efficiently and economically.

The UCI philosophy is to create an environment in which the whole family can enjoy themselves, in surroundings in which they can feel relaxed and which enhance the quality of the movies. Of course, in the cinema industry, a commitment to quality means a commitment to proper sound control and good acoustics. That's where we come in.

The Acoustical Consultant's major concerns can be summarized as:

1. The prevention of excessive sound transmission between adjacent cinemas.
2. The design of room acoustics such that there is no noticeable colouration of the sound track.
3. To control the intrusion of noise from outside the demise of the cinemas and from the air conditioning system.
4. To prevent excessive sound transmission from the auditoria to neighbouring properties.

All of these objectives must be achieved within the context of a project which has economic and time constraints and preferred methods of construction. There are no blank cheques, for all design goals must be achieved without jeopardizing the financial viability of a scheme. We often see our role as ensuring that money is spent where it can be put to optimum use and it is against this background that the effectiveness of any of the acoustical design elements must be judged.

Audio Presentation

Loudspeaker systems in use in cinemas right up until the 1970's and early 80's were originally designed in the 1940's. The design objectives for these systems included a need for high efficiency and for good coverage over the stalls and the balcony. While there was no standard, as such, these common requirements led to a great deal of uniformity in system design and installation between cinemas. They were well matched to the standard mono optical track in use at the time.

The standard of audio presentation that is now achievable in cinemas is considerably improved. Amplifier power is now available in abundance, direct radiator low frequency and mid range drivers are an established feature and high frequency horns with compression drivers have improved considerably. In combination with stereo pick up, well tailored cross over networks and, recently, digital reproduction, cinema goers can benefit from high levels of distortion free, wide–band sound.

UCI cinemas are equipped as standard with Dolby SR playback facilities, the sound systems incorporating sub woofers and surround speakers. Some are already benefitting from a Kodak digital system (CDS) and Dolby digital (SR–D) is due to be made available soon. While the major benefits from digital systems may accrue to the marketing department, the improved dynamic range capabilities will lead to slightly higher programme sound levels. These must be taken into account when designing for sound transfer.

Figure 1 shows typical L_{max} sound levels in a UCI auditorium for a standard sound system, a digital system and also for THX. THX is a proprietary sound system developed by Lucasfilm which incorporates loudspeakers to cover the full audible frequency range, flush mounted in a large, flat baffle together with a specially designed electronic crossover. It produces high programme sound levels across the frequency range.

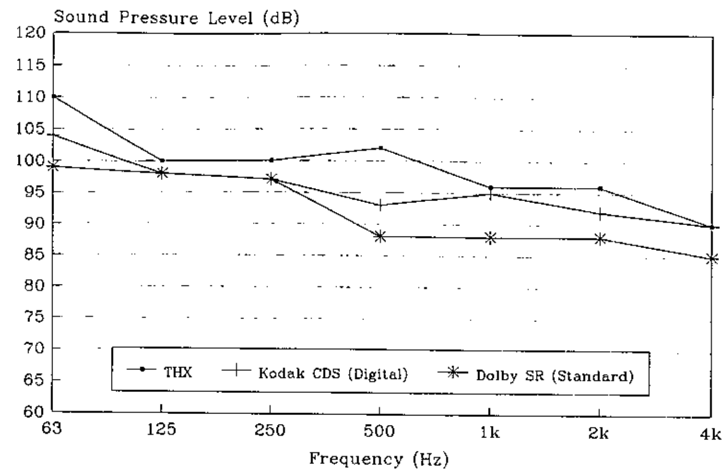


Fig. 1. Typical programme sound levels: Alternative Installations

Sound Isolation

'Sound Bleed' between adjacent cinemas was (and in some cases still is) a major problem in early versions of the multiscreen cinema. It was often the case that a single, large auditorium, normally attracting only a fraction of its capacity, was divided into a number of smaller ones (these are known in the industry as twins or triples). Cost and structural constraints usually led to partitioning which was wholly inadequate in terms of sound isolation. This first foray into multi-screen presentation gave the genre a bad reputation, which is today being overcome by a far more serious approach to the problem on the part of reputable exhibitors. The required degree of sound isolation depends, self evidently, on:

1. The sound levels generated during a screening in one cinema.
2. The level at which residual sound transfer into the adjacent cinema is deemed acceptable.

In the case of the former, the trend in recent years has been upwards, particularly at low frequencies, to the levels indicated in the preceding section.

In the case of the latter, complete inaudibility would seem to be the ideal goal. But such a state of affairs is extremely difficult, and at best hugely expensive to achieve. A digital system with a dynamic range of 90 dB immediately points, notwithstanding background noise from the air-conditioning system, to a sound reduction requirement of the same value across the entire frequency range. Such values could only be achieved through the use of full and effective structural isolation.

Fortunately, practical experience indicates that this degree of separation is not necessary. Some audible residual sound transfer is acceptable, the question is how much?

Figure 2 shows the measured sound spectrum in a normal analogue reproduction cinema for 5 minutes worth of typical sound track. The time varying nature of the programme material is clearly seen by the wide range in levels identified between L_{min} and L_{max} (or $MaxL_{peak}$). For a digital system, L_{max} would be expected to be marginally higher and L_{min} somewhat lower (due to the very low noise floor available with digital reproduction). In practice, L_{min} is often determined, particularly at low frequencies, by the background noise generated by the airconditioning system.

We have indicated that $L_{max} - L_{min}$ (plus 10 dB for complete inaudibility) is not in practical terms required as a sound reduction value. The approach recommended in the THX Instruction Manual is to provide a separation equivalent to $L_{10} - L_{90}$, thus rendering residual sound transfer, the argument goes, audible only 1% of the time. The appeal of this approach toward quantifying the problem is only undermined by one flaw in its logic: the sound spectrum on either side of the partition is not identical at every moment in time.

The quietest periods in the programme often occur during dialogue, when the frequency content tends to favour the mid to high end. The loudest periods are during action sequences or at crescendos in the soundtrack at which time the full frequency range of the sound system is put to good use. Inevitably, low frequency transfer from one screen finds no comparable masking component in the adjacent screen. The problem is compounded by the inability of most typical building constructions to provide high degrees of low frequency sound isolation.

Currently, the design objectives are pitched somewhere between the ideal of no audible transfer and the more pragmatic $L_{10} - L_{90}$ approach.

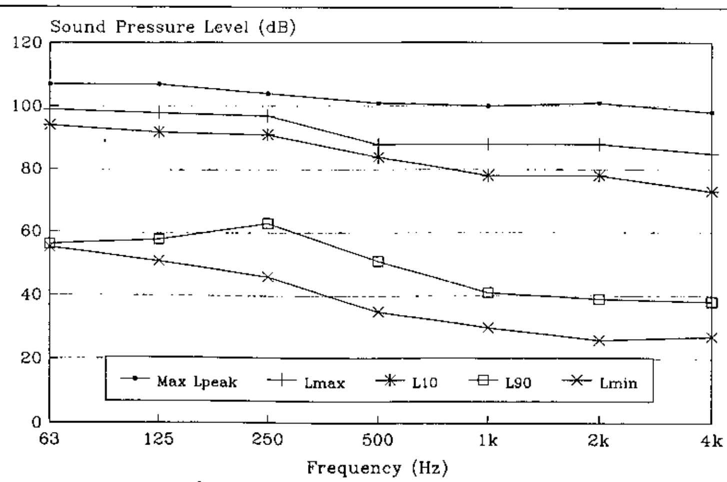


Fig. 2. Typical programme sound levels: Dolby SR Installation

Acceptable sound bleed contains only low frequency components which, while audible, do not degrade the intelligibility of the programme material being presented. Mid and high frequency sound bleed is very distracting and unacceptable. It is indicative of poor design or poor installation, either of which can lead to leakage or sound flanking.

Until 18 months ago, the standard UCI auditorium partition was a high performance double stud wall, with an overall width of 300mm and an installed performance goal of $D_{nT,w}$ = 65 dB. The promise of digital playback systems and the increased use of subwoofers as part of the sound system raised questions about the low frequency performance of the standard system.

The latest cinema to be completed and commissioned in the UK is at Sutton, South of London. Between the auditoria there were large concrete columns which had to be concealed, and this gave us the facility for installing gypsum board partitions with an overall width of 790 mm. The plan configuration is shown in Figure 3. The standard of installation was extremely good and we were able to measure performance figures as high as $D_{nT,w}$ = 82.

This was particularly pleasing in the light of some complicating factors of the basic structure. The cinemas are located directly beneath 5 levels of car park, with the main entrance ramp passing over two auditoria. To accommodate slab movement, the partition heads were designed to incorporate 25 mm deflection joints while maintaining the requisite isolation. It is a golden rule on these projects that good results can only be achieved through teamwork between the acoustic consultant, design architect and partition contractors on site. This project was run on a construction management basis by UCI themselves and was characterized by good coordination, willing cooperation and excellent execution.

Room Acoustics

The most important element of a motion picture soundtrack is the dialogue (Rocky fans please note!). The pre-minent design goal for the auditorium must therefore ensure clarity of the sound track presentation particularly in terms of speech intelligibility. Additionally the space must not lead to any significant 'colouration' of the sound track in order that the audience enjoys the true sound experience as intended by the mixers. However, the characteristics of the auditorium must not be so dead that the sense of room size is completely lost.

These design goals translate into room acoustic requirements as follows:

- Relatively low reverberation times, particularly in the higher frequencies, but not to the extent of deadening the room entirely
- Freedom from detectable discrete echoes and flutter echoes which can greatly diminish speech intelligibility

The design criteria for reverberation time are a function of seating capacity (and therefore room volume) and frequency. Design curves for three sizes of auditoria are shown in Figure 4.

The very high ceilings in the auditoria (which facilitate projection onto the large screens) are a liability rather than a benefit in terms of reflections onto the audience. They are therefore made acoustically absorptive, comprising lay–in fibre glass tiles. The wall behind the screen is also made acoustically absorptive predominantly for the control of phase shifted echoes which could distort the sound radiation from the loudspeakers.

Cinema seats are padded for patron comfort and provide some sound absorption, as does the carpeting in the aisles.

It is no surprise to find that the rear wall is covered, virtually to its full extent, with sound absorbing material. Its distance from the main loudspeakers, particularly in large houses make it a prime cause of audible echoes if not dealt with properly. To treat the parallel side walls in a similar manner, however, would lead to excessive absorbtion. It is preferable that these walls are not covered 100% with sound absorbing material, although coverage must be arranged judiciously if flutter echoes are to be avoided.

A flat, monolithic appearance is preferred for side and rear walls in UCI houses. The acoustic absorption is obtained through the use of surface mounted mineral wool, and an acoustically transparent fabric is stretched over the entire wall surface concealing both the mineral wool and the untreated areas.

Practically speaking, this form of treatment allows us to get close to the design goals. The use of gypsum board for the auditorium walls assists in the control of low frequency reverberation which could otherwise prove difficult if concrete or dense blockwork were used.

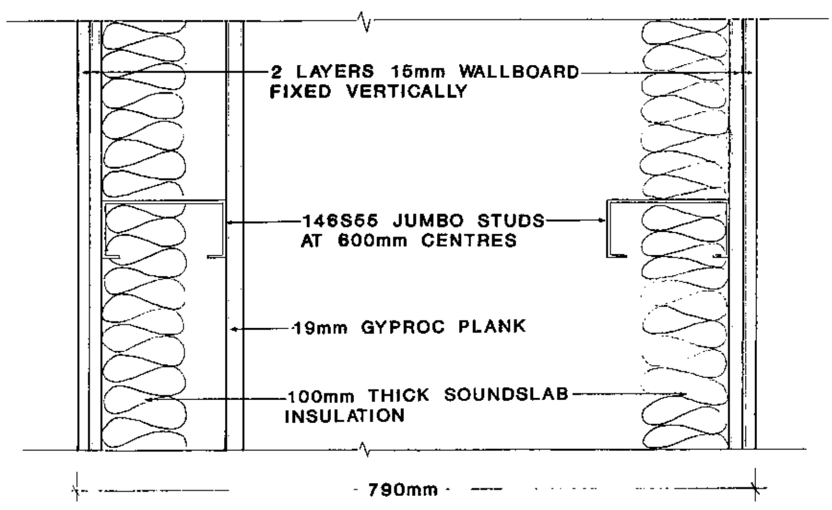


Fig. 3. Drywall Auditorium Partition: UCI Sutton

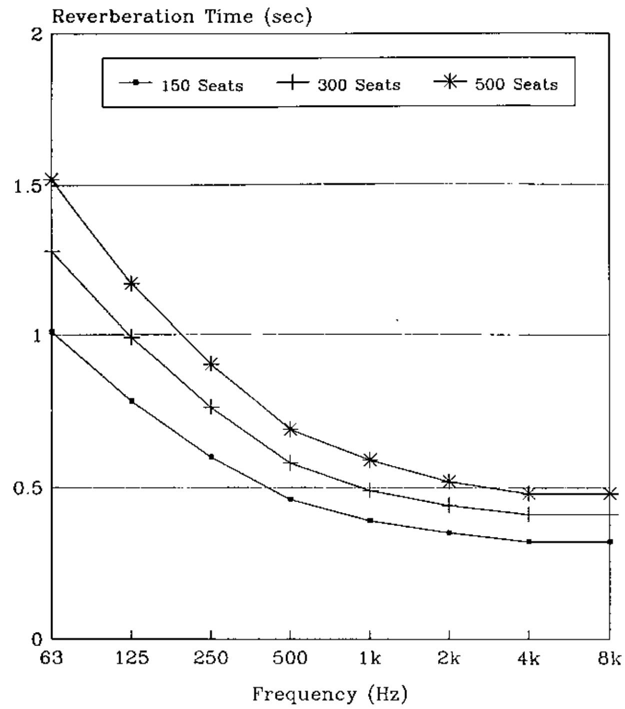


Fig. 4. Auditorium Reverberation Times: Design Goals

Noise Control

Steady state background noise is very useful if it is able to mask sound which is transmitted into an auditorium and would otherwise be intrusive. The correct level of background noise should provide this function without detracting from the enjoyment of the film being screened. The chosen criterion at UCI is NR 30.

THX recommend a design goal of NR 25 (with a maximum allowable of NR 30), and for the largest, most prestigious cinema auditoria we would agree that this is appropriate. The extra expense in achieving the more stringent criterion is exacerbated by the need to improve the sound control of the auditorium envelope. Walls to adjacent cinemas have greater demands imposed on them as do parts of the construction which protect the auditorium from external noise sources. On the other hand, NR 35 can ease the requirements on these elements, although we have found it to a level which is mildly intrusive during a normal screening.

Techniques for controlling air conditioning to achieve relatively low levels are well established and hardly worth repeating here. It is worth pointing out, however, that all auditoria are served directly from above or via the projection suite. Ductwork and piped services are never installed to run between auditoria. This would compromise the performance of the partitions and introduce crosstalk which could require elaborate attenuation.

Practical Challenges

Multiplex cinema developments require low levels of noise intrusion and demonstrably high levels of sound isolation between auditoria. We have already set out the design goals.

In the case of the former, the situation is often complicated by the commercial desire to locate the facility in a complex which is easily accessible and which contains other leisure based attractions. In terms of access, the operator's dream is for a building which is just off a major trunk road or local access motorway and within stepping distance of a public transport stop such as a railway station. Thus the building is hemmed in by a plethora of traffic noise (and vibration) sources. A site which recently became the subject of serious consideration was a building within 5 m of the M1 motorway. Originally developed as a large retail store, the lightweight structure acquitted itself rather poorly in keeping out traffic noise. Unfortunately, or fortunately from our point of view, there were inadequate parking facilities to make the project commercially viable. Sometimes you just feel that you're starting a job with one foot in the grave.

The techniques we are currently employing to control sound transmission between auditoria cannot be applied universally. Much of the experience developed in the UK is rendered inappropriate by the construction codes and practices which prevail in continental Europe.

In Germany, for example, precast or poured concrete often forms a part of the auditorium wall for purely commercial reasons. To erect a gypsum board partition to a height of 8 metres or more requires a structural steel supporting frame of significant proportions and strength. The Spaniards, on the other hand, like to build everything with hollow clay blocks.

Test data on high performance constructions is not always easy to come by (notwithstanding the very useful BBC studio construction data) especially if a mixture of lightweight and heavyweight materials is used. The task of predicting performance is therefore very important, but sadly complicated when unusual or unfamiliar constructions are used.

A final point, relating to the final task we undertake on a UCI project. All cinemas are commissioned in respect of background noise, reverberation times and auditorium sound isolation. We have found it surprisingly difficult to generate sufficiently high levels of source room sound at all frequencies. What we need is 100 to 105 dB in each third octave band for a room whose Krev value varies from 20 to 25 dB over this range. The last test we did utilized a sound rig with 3.2 kW of acoustic power and an amplifier/speaker set which weighed over 400 kg. Yet we could still not generate sound levels as high as we would like at mid and high frequencies.

Powerful PA systems are simply not set up to give a flat output over the test frequency range. There is more than we need at the low end and less than we need at the high. We pay the additional penalty of having to manhandle the extra weight that is part and parcel of redundant bass speakers.

Any ideas anybody?

Vernon Cole MIOA is a Director of Hann Tucker Associates. Hann Tucker Associates is a Sponsor Member of the Institute and a member of the Association of Noise Consultants.

EAST-EUROPEAN ACOUSTICAL ASSOCIATION

The East-European Acoustical Association (EEAA) was officially established at its first Congress in St Petersburg during 4-5 October 1990.

As a public and scientific non-governmental organisation the Association sees its primary goals in promoting creative initiatives among acoustic scientists and engineers, facilitating development of their professional skills, ensuring their social rights and spreading national achievements in acoustic ecology into a world-wide cooperation.

The Congress has elected the President of the Association Prof Dr Tech Sci Viatcheslav T Liapunov from the Krylov Shipbuilding Research Institute (KSRI) in St Petersburg. Dr Tech Sci Alexei V Ionov from KSRI was appointed to manage the department in charge of the Association's international activities.

Due to the political changes in our country the Association took its present name at its Second Congress on 24 April 1992 (the former name was All-Union Acoustical Association).

As a result of the death of Prof V Liapunov the Congress elected as President of the Association Prof Dr Tech Sci Alexei S Nikiforov from the KSRI.

At present about 500 specialists are members of the Association.

The Association includes the following divisions:

1. St Petersburg division (Russia)
   Chairman: The President of EEAA,
   Alexei S Nikiforov
2. Moscow division (Russia)
   Chairman: a Vice-President of EEAA,
   Georgiy L Osipov
3. Kiev division (Ukraine)
   Chairman: a Vice-President of EEAA,
   Victor T Grinchenko
4. Southern division (Nikolaev Ukraine)
   Chairman: a Vice-President of EEAA,
   Georgiy P Nerubenko
5. Kazakhstan division (Alma-Ata, Kazakhstan)
   Chairman: a Vice-President of EEAA,
   Serik S Omarov

Moreover the newly formed Lithuanian Acoustical Society is in the Association. The President of this Society is Danelis Gugas.

The Association publishes a scientific-technical journal *Technical Acoustics* in Russian. The editorial board consists of A S Nikiforov (Editor in chief), E L Myshinskiy (Associate Editor), M Crocker, A V Ionov, T Kihlman, S Kovinskaya (Assistant Editor). An English editionis planned for January 1993. The post-paid price for individuals and libraries is US$95 per year (currently 4 issues) plus US$35 for airmail. For further information, write to: Dr Alexei V Ionov, East-European Acoustical Association, Moskovskoe Shosse 44, 196158 St Petersburg, Russia (Fax. +7-812-1279349)

EURONOISE '92

Imperial College, London:14 - 18 September 1992

Introduction

This conference was first conceived in 1990 as a means primarily of bringing European acousticians and noise specialists together to exchange ideas and views on the European scene but also as a way of testing whether there is a place for a continuing programme of this nature. Indeed it was decided to hold it during 1992 as this was the first available year that Internoise (which generally alternates on an annual basis between Europe and either America or the Pacific nations) was not listed to be held in Europe.

Through the assistance of an international committee under the chairmanship of Professor Geoff Leventhall, a programme of some 120 invited and contributed papers was assembled. The papers were printed in a 1000-page three volume set as Volume 14, Part 4 (1992) of the Institute's Proceedings and available as usual to delegates upon arrival.

The event was held at Imperial College in London and in total 250 delegates from twenty-five countries attended. Thirty of the delegates were from outside Europe and 140 were from the UK. Seventeen companies took stands in the manufacturers' exhibition.

Whilst the technical purpose of the conference was of paramount importance, a social programme allowed ample opportunity for meeting colleagues in an informal manner.

The UK Association of Noise Consultants co-hosted, along with the IOA, a reception on the Monday evening in the magnificent surroundings of the East Hall of the National Science Museum.

The UK Minister for the Countryside and Environment, whose speech is printed below, opened the conference and exhibition and welcomed the delegates.

On the Wednesday evening one hundred and twenty delegates enjoyed a visit by coach to the Thames Barrier and returned to the centre of London by catamaran on which buffet supper was served and acceptable musical entertainment was provided. On the Friday, technical visits took place to NPL, BRE, TRL, B&K and CEL. It was mostly the overseas delegates who enjoyed the hospitality offered by these establishments.

The general consensus among delegates was that the conference had been extremely valuable and clearly pointed to the need for a continuing programme of similar events. Council of the Institute are exploring ways of providing a service to allow this to happen.

Speech given by David Maclean, UK Minister for the Countryside and the Environment

'I am very pleased to be here today to open Euronoise '92, the first pan-European conference to be held on the subject of noise.

This large gathering is evidence of the ever increasing concern about noise as a pollutant. At best, noise creates annoyance and detracts from enjoyment of our environment - at worst it is damaging to psychological and physical health. This Conference will cover all these concerns and I have no doubt that there will be an invaluable exchange of views and experiences on all of them.

Perhaps I can most usefully start the proceedings by looking at the main areas of noise concern and policy in the UK, and the initiatives we are taking to improve our controls over noise. I should like to focus on three main themes - environmental and neighbourhood noise, transport and noise at work.

I am sure that noisy neighbours are a problem all over the world - from Bangladesh to Birmingham. In Britain, as in many other countries, we aim to control environmental noise through legislation. Much is based on the principle of statutory nuisance and requires a local authority to serve a notice on the person causing the noise to either stop or reduce the noise. If this fails,

the authority then has the power to take them to court. Our recent Environmental Protection Act has now imposed a specific duty on local authorities to be more responsive to people's concerns by investigating complaints about noise. Many local authorities have responded by providing either out-of-hours or 24 hour services to deal with such complaints.

Because of the growing concern about noise, the UK Government commissioned an independent Noise Review Working Party to review the existing legislation to control noise from various sources. Its report was published in November 1990 and listed 53 recommendations - over half of them have already been, or are in the process of being, implemented. The Review covered a wide range of subjects - planning and noise, transport noise, noise within buildings, and a growing problem in the UK - large scale noisy parties.

In response to some of the Review recommendations, my Department issued for public consultation in June a document containing proposals to strengthen the law on noise. These include extending the provisions of the Environmental Protection Act to roads and giving local authorities stronger powers to control noise nuisance from audible intruder alarms. I hope this will be welcomed by all those who have been woken up by car alarms at 4 o'clock in the morning. Another recommendation was the need to update our advice on the role of the planning process in minimising noise problems. We published a draft Planning Policy Guidance note last year in response and will be publishing a final version soon.

Of course, we cannot legislate to control all types of noise. That is why we are also working hard to increase noise awareness and encourage more responsible attitudes and behaviour towards noise.

We have contributed towards the running of a noise counselling and mediation scheme in Bristol and will soon start helping to fund another noise mediation scheme in Southwark, south London. These schemes are available to anyone suffering from noise and represent a completely new approach to resolving problems between neighbours without the need for complex legal procedures.

We have also recently funded a pilot neighbourhood noise awareness scheme in Forest Hill, south east London, under the management of Dr Geoff Leventhall. Its objective was to encourage the residents in an area of 1100 households to co-operate in drawing up a code of conduct and agree on standards of reasonable behaviour. The findings show that many residents were made more aware of noise in the neighbourhood and of the action that could be taken to reduce this. We very much hope that other residents' and tenants' associations will seriously consider the possibility of setting up similar schemes in their areas and developing codes of conduct suitable for their neighbourhood.

My Department also grant-aided a project to increase noise awareness among schoolchildren in Nottingham. This is a sound investment - we hope that the children will become responsible citizens, with the extra spin-off of educating their parents. This project was conducted by the Royal National Institute for the Deaf and managed by Steve Carter who is one of your speakers. The results demonstrated that schoolchildren are receptive to this subject, showing genuine concern about pollution in general and the fact that noise could be unknowingly damaging their bodies. At the end of the project, the pupils showed a marked change in their attitude to noise.

We also aim to foster a responsible attitude to listening. We look to manufacturers of audio equipment to take direct initiatives themselves. I was therefore delighted when the British Radio and Electronic Equipment Manufacturers' Association (BREMA) agreed to ask their members to include a reference in their instruction leaflets reminding purchasers about the need to be considerate listeners. I hope people will pay as much attention to this as to the wiring diagrams.

As some of you may know, August was a 'Noise Awareness Month'. The campaign focused on radio stations and promoted the message 'Turn it on - but keep it low'. It was promoted by the National Society for Clean Air and Environmental Protection (an independent body), the Institution of Environmental Health Officers, and a new organisation to the noise scene - 'The Right to Peace and Quiet Campaign'. Their National Co-ordinator - Val Gibson - has in a very short space of time taken this campaign forward and achieved an impressive national membership of people who are either victims of, or generally concerned about, neighbourhood noise. It may be that the UK has achieved another 'first' here in terms of the formation of an organisation specifically created to stand up for the right, which so many people want, to have peace and quiet.

Transport

Let me turn now to transport. Noise from road traffic is a frequent source of complaint. At lower speeds, the noise comes mainly from the engine; at higher speeds, the problem is largely one of tyre noise. The proportion of heavy lorries and the texture of the road surface can significantly affect tyre noise. Although the proportion of goods vehicles on the road is unlikely to increase significantly over the next 15 years, more goods will be carried in heavier lorries. The Government is therefore looking at ways to reduce noise from both engines and tyres.

There are clear benefits to local communities of diverting long distance traffic onto new and improved roads. When a new road is designed, we aim to reduce the impact of noise by choosing a route away from residential areas and by making the best use of the existing landscape to exploit any natural screening. There is scope to reduce noise from existing roads through barriers, such as earth mounding or acoustic fencing, and the use of alternative surfaces, such as porous asphalt. The Department of Transport plans to publish a guide to environmental barrier design later this year.

My Colleague, Kenneth Carlisle (Minister for Roads and Traffic), announced in July a new three-point initiative aimed at tackling the problem of road noise. First, roads and motorways with heavy traffic will in future be surfaced with asphalt until improvements can be made to the smoothness of finish obtainable on concrete surfaces; second, in urban and noise-sensitive areas, porous asphalt will be used where practicable and third, further research will be undertaken on quieter surfaces. This will include evaluation of the cost-effectiveness of a number of surfacing techniques which have recently been introduced abroad.

Since joining the European Community, the UK has incorporated the relevant motor vehicle noise directive into national regulations. Last year, the Commission proposed a revision of the vehicle noise directive which will reduce the noise limits for cars and for the largest HGVs. The Government especially welcomes this proposal which is consistent with our long-term aim of reducing noise from road vehicles.

A major source of public complaint is noise from motorcycles. As with cars, we are committed to introducing the tightest feasible noise limits for all new machines. The European Community has been working on a new draft noise directive. This will have the effect of tightening the limits in the existing directive for mopeds in 1996 and motorcycles in 1998.

In the White Paper on the Environment, we made a commitment to review existing powers to control aircraft noise. We published a consultation paper last year which proposes changes in legislation to place airports under an obligation to produce a scheme to reduce noise from aircraft landing and taking off. We have also asked for views on noise problems from ground activities at airports and from helicopters using temporary landing sites.

Two subjects on your agenda which are of particular interest to me and my colleagues in the Department of Transport are the use of Leq as an aircraft noise index, and the relationship between aircraft noise and sleep disturbance. In September 1990, the Government announced its decision to change to Leq to measure people's exposure to aircraft noise. It is a widely used measure of noise exposure and is the basis of many indices of noise from aircraft, road traffic and industrial premises worldwide.

Many people living near airports are affected by sleep disturbance and we have commissioned a major research project into this. You will be hearing about the techniques employed in the fieldwork. The results of the research are still being analysed but will be used to make decisions on night restrictions at major UK airports in the coming years. I hope they will also be of considerable interest to other countries.

Noise At Work

In the UK, we have an independent Health and Safety Commission responsible for advising Government on such matters, including noise. It works through the Health and Safety Executive (the HSE). The Commission and HSE are the responsibility of another of my Ministerial colleagues - Patrick McLoughlin - who is Minister at the Department of Employment.

The HSE does much to protect workers from the health damage which noise can create. As this is to be a major theme of your Conference, I should like to conclude by telling you about its work and recent initiatives.

It is estimated that over 1.5 million workers in British industry work in noise levels which can cause damage to hearing. Indeed, noise-induced hearing loss is one of the most common industrial diseases. Many sufferers cannot be treated effectively and are forced to live their lives almost in isolation, often misunderstanding their work colleagues and avoiding situations where they cannot hear properly. For some, there is the added distress of permanent tinnitus.

Noise-induced hearing loss is also extremely expensive for British industry, not only through lost production, caused by sickness, but also from compensation awarded against employers. Although no official figures exist, it is safe to assume that such payments run to many millions of pounds a year.

Considerable progress has been made to reduce workplace noise. Official guidance was first produced in Britain in 1968. In 1986, the European Community adopted a directive on the protection of workers from noise. Then at the beginning of 1990, the UK implemented the Noise at Work Regulations with the help of the Health and Safety Commission. The main measures include the assessment of noise hazards; information for workers; noise control; the provision of personal ear protection, and the provision of information on noise levels by machinery suppliers. The Regulations are supplemented by guides and leaflets.

This new law has allowed HSE inspectorates to press employers to reduce risks arising from noise. In the first two years of implementation, some 1200 improvement and prohibition notices were issued requiring employers to take specific action to address the problem of loud noise.

HSE also hopes to play a significant part in altering perceptions to noise through information and education. Many employers understand the hazard but few are prepared to take positive steps to protect their employees. Conversely, workers often have to be encouraged to wear ear protectors for their own safety.

The UK Government's push for action has been given added impetus this year as noise has been identified by the European Commission as a priority during the European Year of Health and Safety. HSE has played a vital co-ordinating role in publicising the year and assessing applications for funding projects from outside bodies. It has initiated a number of interesting and valuable projects which I am sure will be of interest to you. Let me briefly describe a few.

Firstly, HSE have produced a touring exhibition called the 'Noise at Work Roadshow' to encourage people to value their hearing and understand how it can be damaged by exposure to noise. The exhibition also shows what can be done to control noise. The aim is to make people aware of the risk of hearing damage and encourage them to take steps to prevent it.

Secondly, HSE has continued its campaign to increase awareness among young workers of the dangers of loud noise and that you don't have to be old to suffer hearing loss. Following an earlier project in Scotland, the campaign, which used both radio and press advertising, was extended into the Midlands during the Spring.

Thirdly, HSE has sought to influence the perceptions of schoolchildren. Through the widely respected and well supported Young Engineers for Britain competition, HSE has sponsored prizes for projects which offer the best engineering solutions to control noise at work. HSE hopes that such sponsorship will encourage pupils to develop interesting and creative solutions to existing problems, and to take these lessons forward into their working lives.

Lastly, HSE has gone into partnership with the Royal Society for the Prevention of Accidents to produce a teachers' pack on noise for use in secondary schools which will be linked to the National Curriculum. The aim is to teach children about the hazards and irritations caused by noise at work and in their social environment.

Of course, industrial noise is not solely responsible for hearing damage. Any exposure to loud sound including shooting, loud music and other noisy leisure activities can put hearing at risk. Public expectation and demand for quieter products and lifestyles exert a powerful force on manufacturers and suppliers to provide quieter goods. Supported by concern from employees and the general public about the risks industrial processes have on hearing, the increasing importance of environmental issues seems bound to have considerable influence towards attitudes to noise. Recognising this, HSE is soon to publish guidance on the health and safety aspects of mounting pop concerts which will include advice on the control of noise.

Conclusion

I am sure that this conference will provide a good opportunity for experts from the many countries represented here today to exchange their ideas and share the results of their experience and research with colleagues. I hope that it is a great success and proves to be the first of many such conferences.'

Plenary Lectures

Marcel van Der Venne

In his invited paper Marcel van der Venne who is the principal administrator within the EC Commission responsible for occupational noise matters, gave a concise and informative review of the rationale behind present and future EC Directives on noise at work. He described the thinking behind the draft Physical Agents Directive, which is intended to replace Directive 86/188/EC, and highlighted the major areas of change, including the move to a C-weighted peak criteria. In so doing, M van der Venne gave a fascinating and informative insight into the legislative process within the EC Commission.

Sandy Fidell

Sandy Fidell's invited paper on the subject of community response to environmental noise was an object lesson in both clarity of exposition and identification of critical issues in a much discussed area of subjective acoustics.

In an enjoyable and highly informative presentation, Dr Fidell reviewed the psuedo-analytical approach to annoyance prediction which gave rise to the Dosage-Response relationships used in USA planning studies, before going on to highlight the variance in such data. He concluded by discussing current work by BBN in the assessment of aircraft noise in wilderness areas, showing a series of impressive graphical representations of noise intrusion.

A Dudley Wallis

After being introduced in a skilfully amusing manner by the acting chairman Geoff Kerry, Dudley Wallis gave a comprehensive survey of the history of sound measurement with particular reference to the development of instrumentation. The 'mahogany' of the title refers to the case material of the early instruments; they were made of 'glass, metal and mahogany'. The temporal range of Dudley's paper started with Pliny the elder who compared city noise levels 20 centuries ago using two sound level indicators located on either side of his head (!) dealt with the rapid development of sound level meters and finished with a view of the future, and to some extent the present, use of computers and software to outdate the stand alone sound level hardware.

The speaker was at pains to apportion the credit for the successes in instrumentation over the years to the several companies involved and made little, but naturally some, attempt to highlight Cirrus's contribution.

The talk was both informative and very entertaining and the audience showed its appreciation enthusiastically. Readers are recommended to obtain a copy of the proceedings and read the full written paper.

Session Reports

Living with Leq

Chairman John Large

This session was organised by the UK Association of Noise Consultants and the contributions can be divided into two categories. The first outlines the environmental noise regulations in several Europen countries. Perhaps the most curious was the paper given by Hugo Verhas, 'Environmental regulations on industrial noise in Belgium'. He outlined the very complex draft regulations for the Flemish speaking section of Belgium. There are apparently no plans for such regulations in the French region.

Dr Beckenbauer's paper, 'Living with L_{eq} in Germany', provoked much discussion from the German members of the audience who concluded that the existing indices were old fashioned and over complex. The rest of the audience were rather surprised at the vehemence of the arguments and obvious polarisation of opinions. The Swiss noise standards outlined by J Rabinowitz are comprehensive and detailed although they seemed to have little relationship with other European standards.

The second set of papers were on domestic issues and covered a wide range of topics. One conclusion threaded through all the papers, that is that L_{Aeq} provides a reasonable description of the acoustical environment but other factors, particularly of a non–physical and socio–economic nature greatly influence the level of annoyance. Reference to this fact was also made by Robert Hood, 'The use of L_{eq} as a description for baseline noise levels', John Walker, 'The application of L_{eq} to railway noise' and R Cadoux, 'The use of L_{eq} as an aircraft noise index'. The latter showed a revealing graph which related percentage of population highly annoyed to L_{eq}. This graph indicated the wide range of response for a given level of annoyance.

The last four papers of the session covered a wide range of activities. There was a lively discussion after the presentation on pop concerts with several members of the audience doubting the validity of the measure for this type of environment.

The last paper, 'Assessment of noise from motorised water sports' by T A Curson, ended on rather a sad note with the author indicating that the latest draft paper on leisure activities had removed any reference to water sports even though earlier drafts had suggested a peak level as an appropriate guide.

Industrial noise

Chairmen Peter Hunnaball and Stuart Bennett

Murray Hodgson opened the morning session with an instructive overview of his wide experience in the prediction of reverberation times in industrial buildings.

Stephen Dance and Bridget Shield continued this subject with a comparison of the Raycub model with the CISM method they developed at South Bank University showing improved accuracy and reduced calculation time with the CISM technique.

Noise reduction with rubber, when used as a constrained layer, was found to be related to the mechanical properties of both natural and synthesised rubber, as explained by H R Ahmadi of Malaysian Rubber Research.

The process of fan noise minimisation by correct selection of fan type and careful installation was detailed by Peter Hunnaball of Woods of Colchester including an explanation of the internationally recognised fan installation codes.

Keith Broughton demonstrated the benefits of a unique noise damping process provided by laser cut, epoxy filled, profiles that subdue 'circular saw' noise. These have resulted in large reductions in noise level in a range of applications, demonstrated during tests sponsored by the HSE.

Malcolm Crocker explained clearly the background, procedure and practical use of sound intensity measurements when used for sound power analysis under both controlled and 'real' working environments. Sound intensity showed good correlation with traditional pressure techniques but reduced the problem of the influence of background noise.

Active noise control was the opening subject for the afternoon session. Firstly M O Tokhi of Sheffield University spoke on the implementation of adaptive active noise control systems using digital signal processing devices. This was followed Mingsian Bai of the National Chiao Tang University of Taiwan who gave a paper on control based active noise cancellers for ducts. Geoff Leventhall, Digisonix, summarised the present physical applications of active noise cancellation and predicted wide ranging future applications, some at present under development.

J Thome outlined a very detailed prediction method for noise sources developed in France under a government sponsored project indicating the future potential for this powerful technique.

David Bull of Colchester Institute provided a lively presentation on the Certificate of Competence in workplace noise assessment, particularly the delivery and industrial application as Colchester Institute provide it. Stuart Bennett, British Coal. TSRE detailed the work carried out on the problematic identification and control of low frequency noise from large reciprocating coal screens.

The final paper of the day described a method used at the Tatra Company in Czechoslovakia to analyse gearbox vibration using time domain techniques.

All the presentations were well received with relevent questions following each session; the quality and content of all papers were of a high standard.

Noise standards.

Chairman Bernard Berry

All the papers in the morning part of the session were concerned with machinery noise standards. For the first 5 of these we had the benefit of contributions from members of key working groups of ISO Technical Committee 43/Sub-Committee 1.

Roger Higginson of NPL opened the session with a comprehensive summary of the extensive activity within ISO and CEN in response to European legislative requirements relating to machinery noise emission, in particular the machinery safety Directives.

The paper by Jean Jacques of the INRS at Vandoeuvre dealt with standardization work in progress on the contents of noise test codes and of the noise clauses in safety Standards.

In his paper, Hans Jonasson from the Swedish National Testing and Research Institute in Boras, explained that having a noise test code is not enough. Guidelines on the use of the measured data are also necessary. He went on to describe the current status of Standards for declaration and verification of noise emission values.

The paper by Gerhard Hubner

from Stuttgart University was concerned with the ISO Draft Standard on 'Rules for drafting and presentation of a noise test code'.

In a joint paper, Knut Skovgaard of the Danish Acoustical Institute and Lief Nielsen of the Danish Standards Association, described work in progress on noise control standards, dealing with the design of low-noise machinery and low noise workplaces, the systematic collection of noise emission data, and the performance of noise attenuating devices.

In his paper Peter Hanes of NPL pointed out that although work is underway in the revision of the ISO 3740 series of Standards to harmonise and clarify the clauses on measurement uncertainty, there is still a lack of comprehensive data on the reproducibility of measured sound power levels. He outlined work completed, and further work planned at NPL, to provide this data. In the final paper of the morning, Jolanta Koton from the Central Institute for Labour Protection in Warsaw discussed work on the noise declaration of machinery aimed at harmonising Polish Standards with ISO and EN Standards with a view to implemention of EC Directives.

In the afternoon, the session moved to more general issues of standards for environmental and transportation noise, and health and safety.

With a view across Europe and beyond, Nicole Porter of NPL gave a fascinating insight into the similarities and differences between standards used in 14 countries for the assessment of industrial noise. The paper looked at ways in which ISO 1996 has been implemented.

Pietro Romani from the Italian high-speed railway company described a study of the noise impact of the new line from Milan to Florence.

Giovanni Semprini from the Istituto di Fisica Tecnica in Bologna reviewed important changes in the traditional framework of Italian legislation, in the form of laws enacted in 1991 on noise exposure limits (outdoors and indoors), and work place noise. The laws on environmental noise exposure indicated a comprehensive approach but seemed complex and ambitious.

In a presentation which, in form and content, represented a significant and memorable departure from normal conference papers, Olaf Alberts from the Dresden office of Cirrus Research plc, gave a very moving, personal and thought provoking exposition on his thoughts as a German acoustician during and after unification.

Harry Lester from HSE Bootle then described the background to the first European Conference of Government Noise and Vibration Specialists in January 1991, and went on to consider the issues discussed, resolutions agreed and arrangements for further exchange of information and co-operation. The paper led to an interesting discussion on the topic of hearing protectors for orchestral musicians.

Bridget Hay of Coventry University gave a very informative account of EC Health and Safety legislation relevant to noise at construction

sites, and hammered her message home most persuasively with a video (nasty?) of construction site noise sources and activities. The last paper by Gustav Sehrndt from the Bundesanstalt fur Arbeitschutz in Dortmund, returned to the topic of machinery noise standards and was concerned with the specifics of the 'local environmental correction'.

Transport Noise.

Session Chairmen: Graham Parry & Jon Pyke

This session was exceptionally well attended both for the morning and afternoon periods.

The session was opened by the Chairman, Graham Parry of DnV Technica who gave the first paper entitled 'The European high speed rail network-environmental impact assessment and noise including the UK experience'.

The paper was well received and the Chairman in an effort to ensure that the session ran to time decided to move on to the next paper without taking questions.

Nick Antonio of Arup Acoustics proceeded to give an exceptionally well illustrated paper on 'Engineering prediction of railway vibration transmission in buildings'. The paper considered a variety of building designs and locations with respect to rail noise and vibration. Of particular interest was the amplification effect of 1 dB/floor for the range 4 to 16 Hz and an attenuation effect of 1 dB/floor between 63-125 Hz. The paper prompted a number of pertinent questions from the audience, not least from Peter Grootenhuis and Bob Hood who are acknowledged experts in the field.

Patrick van de Ponseele of LMS Belgium gave a very interesting paper on 'In room exterior pass by noise'.

The paper described the measurement of pass-by noise by the use of a semi-anechoic chamber large enough to contain a vehicle and a chassis dynamometer. This allowed the operation of vehicles under realistic simulated driving conditions, free of the restrictions normally imposed by the weather in outside test sites. Whilst the solution was expensive it appeared to allow greater control in respect of speed, gear and acceleration characteristics. Of the many questions from the floor, of particular concern was the actual noise from the rollers, however it was subsequently reported that this contributed only 40 dB at the centre of the vehicle.

Rein Muchall of Amsterdam gave probably the best illustrated paper of the day with an enormous amount of information. His paper 'A traffic noise and air pollution atlas as a research instrument for environment policy in Amsterdam' described in detail the Dutch noise policy and national insulation program. Regrettably despite frantic arm waving from the Chairman the paper overran by 20 minutes and there was no time for questions as the delegates were then keen to rush to lunch.

The afternoon session started with Isobelle Vernet's paper 'Efficiency of road noise barriers with respect to residents'. The paper was well documented with respect to annoyance but, as it was given in French, some of the delegates may have lost the overall thrust of the research and conclusions. The Chairman was one of the few people present able to ask a question not least because he had an English translation of the paper.

The afternoon session continued with some excellent papers entitled 'A digital measuring concept as a means of traffic control', 'Aircraft noise and sleep disturbance - a field study', 'Health implications due to sleep disturbances around airports', 'The airline contribution to noise reduction', 'Noise levels of helicopters performing elevated pad take-off and landing procedure'.

All of the papers provoked a great deal of interest and in particular the work of Ceril Jones of the CAA on 'Aircraft Noise and sleep disturbance' - The presentation described the use of actimetry, calibrated against EEG records, to determine sleep disturbance matched with actual noise measurements of aircraft.

The final paper of the day was given by Bernard Postlethwaite and described the studies carried out on helicopter noise to determine the noise and operational characteristics of a proposed heliport alongside offices adjacent to the Thames. Extensive measurement studies at a controlled location had yielded particularly interesting information with respect to noise levels away from the direction of take off and the sound propagation factors.

The final paper resulted in a great deal of interest and questions from the floor and was representative of the high standard which had been maintained throughout a worthwhile and informative day.

Environmental Noise

Session Chairmen: John Sargent & Geoff Kerry

A wide range of topics was covered in the Environmental Noise sessions from the subjective assessment of noise to educating children about noise and from planning against noise in busy cities to aspects of noise from windfarms in rural areas.

The first session started with papers dealing with planning and policy for noise control with papers presented by John Hinton on noise control in Birmingham, Sam Wong on planning against transportation noise in Hong Kong and Colin Grimwood on the use of noise abatement zones.

Attention then turned to the subjective assessment of noise. The results of work on annoyance due to tonal noise which has been carried out at ISVR was presented by Prof Robinson and the work currently in progress at NPL on the assessment of industrial noise was presented by Bernard Berry. The use of free number magnitude estimation to measure annoyance was discussed in a paper by Summers & Howard-Jones. The use of 'C' weighted levels to take account of the low frequency noise from the docklands light railway was shown in the paper by Shield and Zhukov to give better correlation with annoyance than 'A' or 'B' weighted levels.

Criteria for helicopter noise were discussed in papers by Bloomfield & Shield, and Weston.

The development of a measuring

system which will automatically record the contribution of noise at a measurement position from a number of different sources such as a road, a railway and aircraft was giving in a paper by Flindell & Wright. A paper dealing with an improved method of predicting noise from open sites, such as surface mineral workings, was presented by Roger Tompsett.

The effect of noise sources in rural areas was discussed in papers about noise from wind turbines by Mackinnon & Henderson and McKenzie. The control of motor sport noise was described by Andrew Watson and noise from model aircraft by Bob Lorenzetto.

A preliminary study into the effectiveness of an educational approach to increase the awareness of children to the effects of noise was presented by Brian Grover.

A paper on behalf of the Right to Peace & Quiet Campaign presented by David Symons gave the lay person's view of how environmental noise should be improved.

The session concluded with a presentation by Ken Dibble showing the improvements to the structure of a discotheque in Nice which were made to reduce the noise transmitted into the neighbourhood.

Instrumentation

Session Chairmen: Dr Ian H Flindell & Ralph Weston

The session took up most of the day in one of the two smaller lecture theatres. Attendances varied from nearly full down to about twenty five, depending on the various attractions of the alternative parallel sessions. A number of the speakers represented commercial organisations with particular instrumentation products, yet almost all of these speakers are to be commended for avoiding an overt marketing approach, preferring instead to concentrate on significant aspects of the technology and the underlying advantages and disadvantages of the different possible approaches.

The first speaker was Tom Clark, of Hewlett Packard Limited, Test and Measurement. Tom described the capabilities of modern digital signal processor chips, such as the Motorola 56001 and 96001, which can implement complex filter algorithms in relatively low cost hardware under software control. This means that it is now possible to implement complex measurements such as EPNL, as used for aircraft noise certification, in real time. Tom further described a method to distinguish between ground plane reflection effects and true tonal components when assessing the tone correction incorporated into the EPNL method.

The next speaker was Bob Selwyn, of Lucas CEL Instruments Ltd, who described a personal view of the role of the portable personal computer in acoustic measurements. Bob discussed the different amounts of data obtained by sampling the complete audio signal at 50 kHz, as compared to sampling an analogue RMS detector output at say, 80 Hz to ensure a good representation of the F-weighted time history. He concluded that with current technology the personal computer is best employed in a secondary or tertiary processing role, leaving the RMS detection functions in the analogue domain.

John Carey, of Larson Davis Laboratories, described some of the more interesting capabilities of a range of data logging portable frequency analyser systems which are seemingly capable of considerable flexibility given the right programming. John discussed the possible advantages of storing a number of different 'inbound' and 'outbound' spectra, as triggered at different threshold levels, for use in the discrimination of particular noise events, such as individual aircraft type flyovers. Other possibilities included Ln statistics across different frequency bands for use in the identification of steady pure tone components in a fluctuating background noise, or for setting industrial noise limits for minimum community disturbance at the lowest noise control cost.

The last paper before coffee was given by Monsieur J P Fanton, of Electricite de France. Monsieur Fanton described a complex robot system which can be used to determine the sound power output and directivity pattern of industrial power machinery. The robot manipulates an intensity probe in three dimensions around the test object, and is further capable of three orthogonal rotations at each grid point. The main advantages of the robot over manual methods are that a high density grid can be defined, without incurring the loss of accuracy and repeatability associated with human operators, and the avoidance of safety risks. There were also a number of difficulties which would need careful consideration if the method were to be taken up more widely.

Duncan Jarvis, of the National Physical Laboratory, discussed the problems of ensuring accurate calibration over a wide frequency range for acoustic intensity probes to ISO 9614. The relative phase difference between the two pressure microphones used in a typical intensity probe is very important for measurement accuracy at low frequencies, and this can be adversely affected by low frequency venting. There are a number of problems involved in each of the different available methods of intensity probe testing. For example, a standard intensity piston phone does not take microphone low frequency venting into account. Verification tests should be performed on a complete instrument (probe and signal processor) to ensure reliable results.

W R Hodson, of Topexpress Limited, described a new method for the analysis of noise transmission in complex structures. The method was developed for the analysis of multiple noise and vibration transmission paths in ships, where it had been found that noise control treatment or vibration isolation often gave unpredictable results due to the effects of the vector addition of signals arriving by alternative transmission paths. A system has been constructed based around measuring a transmission path matrix using a multiple transducer array (accelerometers and microphones as appropriate). The system has been found to be very useful in identifying the most important transmission paths for noise control treatment.

Duncan Brown, of Cirrus Research plc, described the various capabilities of the ARIA measurement system. This system is based around a digital signal processor card installed in a personal computer which is capable of a large range of different functions depending on installed software. The basic philosophy is to use the DSP card for signal acquisition and primary processing, reverting to the PC processor for statistical functions, mass data storage, and the production of presentation quality output charts and reports. This enhances functionality at a relatively low hardware cost.

After lunch, Charles Horton, of Humberside County Council, described the aircraft noise monitoring system installed at Humberside International Airport. This was installed under the terms of a planning condition imposed as part of a consent to extend the runway in 1989, in response to concerns over aircraft noise expressed by the local population. A permanent noise monitoring terminal (NMT) was installed on land already in airport ownership and used for runway approach lights at each end of the runway. A portable NMT is used for monitoring at community sites. The main advantages of the system were felt to be that it demonstrates official interest in noise control, that unusual events can be detected and recorded, and that a valid statistical database will be produced that can be used for future planning.

Ernst Siegfried, of the Swiss Federal Office of Metrology, described a recent international inter comparison of standard half-inch microphone calibration standards. Participating laboratories calibrated three microphones over a frequency range from 125 Hz to 25 kHz using reciprocity. Two microphones from each laboratory were then compared at the UK National Physical Laboratory against a further standard microphone. The work showed that calibration uncertainties of hundredths of a dB were achievable at low and mid frequencies, rising to tenths of a dB at high frequencies. Bearing in mind national policies on the traceability of calibration standards via working standards, this means that national laboratories must continue to take exceptional care to maintain accuracy.

Paul Darlington, of the Department of Applied Acoustics at Salford University, discussed the practicalities of developing an all-digital hand held sound level meter system using DSP chippery. The problems arise from the signal processing load required to implement the standard time and frequency weighting filters and energy accumulation at a 60 kHz sample rate and with a worthwhile dynamic range. Modern DSP chips can fulfil the computational load, but until recently at a greater hardware and energy cost than the best analogue circuitry. However, the current cost of integrated circuits is reducing all the time, which means that we will soon be able to take advantage of the increased reliability, performance, and accuracy inherent in DSP techniques.

Manfred Zollner, of Cortex Electronic GmbH, described an approach to the direct measurement of loudness, annoyance, and sound quality using complex signal processing. The main emphasis of his talk was the demonstration of a number of acoustic features that have been found to influence subjective sound quality, using a DAT recorder and loudspeaker system. Having a range of sounds to listen to is always welcome at an acoustics conference.

Overall, the instrumentation session proved to be most interesting and pointed the way in which acoustic measurement systems are likely to develop in the future. There is an emphasis on the use of Digital Signal Processing (DSP) chips which will allow future hand held instruments to include powerful real time signal analysis techniques as soon as the cost and electrical power requirements become competitive with existing analogue techniques.

The instrumentation session was then followed after tea by an open session of three papers. Mr Strahinja Trpevski from the Institute of Civil Engineering at Skopje, Yugoslavia, described a successful approach to town planning which separates much of the road traffic noise resulting from the transport policies of all industrialised countries from the communal living space. The concept requires town planning in neighbourhood units which are large enough for communal facilities such as child care and play areas, but not so large to restrict access to the nearest roadway.

Mr C He, of the University of Kaiserslautern, Germany, described his experimental work on the acoustic effect of micropore mufflers on pulsed jets and ring jets, for possible automotive applications. Honeycomb micropore mufflers can provide significant attenuation with minimal flow losses and with simple construction.

Dr Hardial Sagoo, of Mott MacDonald (Highways) gave the final paper of the day on the assessment of noise from road traffic on dual carriageways. He described work on the potential errors introduced when calculating road traffic noise levels using the approved CRTN method. The CRTN method specifies that a single source line should be used except where multiple carriageways are separated by more than defined distances. Under these circumstances, the CRTN method predicts greater benefits from noise barriers than would result from calculating the effect of the barrier for each carriageway separately. Dr Sagoo gave examples of situations where the difference would significantly affect entitlement to noise insulation.

Building Acoustics

Chairman Les Fothergill

This session was well attended, and the audience was rewarded by ten interesting and well presented papers covering a wide range of topics. Bernadette McKell (Robin Mackenzie Partnership) described a screening test for the insulation of floors against impact sounds. This is of great current interest as European Standards for short tests are being developed and there is much discussion on the accuracy required. M L S Vercammen (Peutz Associes BV) dealt with an aspect of structure borne sound not yet covered by standards - predicting the SPL in a room from from the source strength of a machine. He described a reciprocal substitution method which was simpler than the direct substitution method but gave similar results for concrete floors.

David Oldham and H A Akil (Liverpool University) were concerned with the difficulties of predicting SPL in factory buildings. A successful ray-tracing method introduces the 'scattering cross section' of objects, which is difficult to determine. The authors proposed a reasonably simple iterative procedure based on reverberation chamber measurements.

The next two papers dealt with the prediction of noise outside factories clad with profiled metal sheets. Maria Heckl (Keele University) described the first stage of a powerful theoretical model for periodic structures, based on Hamilton's principle and Bloch's theorem. R M Windle and Y W Lam (Salford University) described their investigations of poor mid-frequency sound reduction of profiled cladding. They concluded that the dips were due to radiation from specific modal vibrations that do not undergo near field cancellation. They have developed an empirical model and are working on the theoretical basis.

D J Oldham (Liverpool University) and X Zhao (UMIST) turned their attention to 'measuring' cracks in buildings which allow air leakage. They used acoustic intensimetry and were able to size simulated 'straight through' cracks quite accurately, and proposed a method for more complex crack shapes.

Mike Wilson (North London University) gave an informative review of acoustic problems in buildings employing passive solar design to minimise fossil fuel consumption. Requirements for natural ventilation conflict with sound insulation, but great energy savings are possible.

R Lyons (Liverpool University) described how coupling between rooms reduced the accuracy of SRI measurements at low values, as found with louvered screens used to enclose machines that need ventilation. He has applied the impulse method to this situation and found reasonable accuracy, even with double screens. R D Sullivan and Barry Gibbs (Liverpool University) have applies SEA to investigate the insulation of diaphragm and fin walls. Neither design is well suited for providing sound insulation, but they are working to find ways of improving performance.

M K Ling and Tina Emmanuel (BRE) are also using SEA, this time to develop a model of sound insulation between dwellings. The theoretical work is being carried out in parallel with experimental work in a new laboratory designed to investigate flanking transmission. Results for simple cases were encouraging.

Acoustic Modelling

Chairman: David Oldham

The first paper was presented by K A Hussain of MIRA and discussed errors in the low frequency boundary element analysis of cavity acoustics. The second paper described work on the prediction of the absorption coefficient of perforated faced porous absorbers given by C Verhaegen from Leuven. The comparison between predicted and experimental results was very impressive.

The last two papers were delivered by C McCulloch from Dynamic Structures and Systems of Sheffield and described the application of two advanced software packages. The first was concerned with FEM and BEM acoustic models and the second with use of the conical beam method in architectural, industrial and environmental acoustics. ❖

News from BSI

New and Revised British Standards

BS 7585: Metallic multilayer plain bearings
Part 1: 1992 Method for non-destructive ultrasonic testing of bond. This specifies an ultrasonic test method for determining bond defects between the bearing metal and the backing on metallic multilayer plain bearings with layer thickness greater than or equal to 0.5 mm. No current standard is superseded. It is equivalent to ISO 4386-1.
BS 6840: Sound system equipment
Part 15: 1992 Specification for matching values for the inter-connection of sound system components. This edition introduces technical changes to bring the standard up-to-date but does not reflect a full review or revision of the standard, which will be undertaken in due course. It implements CENELEC HD 483.15 S3 and supersedes BS 6840: Part 15: 1998 and is equivalent to IEC 268-15.
BS 7850: Total Quality Management
Part 1: 1992 Guide to management principles. This gives guidance to management on ways to make the organisation structure, management and quality system more effective in meeting organisational objectives by maximising its human and material resources. No current standard is superseded.
Part 2: 1992 Guide to quality improvement methods. This gives guidance to management on ways to facilitate and promote continuous quality improvement. This fundamentally affects the ability of an organisation to compete and the ability of its members to contribute, grow and excel. It contains many useful techniques for the application and measurement of quality improvement. No current standard is superseded.

BS EN Publications

The following are British Standard implementations of the English language versions of European Standards (EN's).
BS EN 29052 Acoustics – Method for the determination of dynamic stiffness.
BS EN 29052-1: 1992 Materials used under floating floors in dwellings. This specifies test method for determining the dynamic stiffness of resilient materials used under floating floors. It applies to the determination of dynamic stiffness per unit area of resilient materials with smooth surfaces used in a continuous floor layer under floating floors in dwellings. It does not apply to loadings lower than 0.4 kPa or greater than 4 kPa. It is equivalent to ISO 9052-1 and no current standard is superseded.
BS EN 20140 Acoustics – Measurement of sound insulation in buildings and of building elements.
BS EN 20140-10: 1992 Laboratory measurement of airborne sound insulation of small building elements. This applies to building elements excluding windows and doors, with an area of less than $1 m^2$ and which occur in a certain number of discrete sizes with well defined lateral dimensions and which transmit sound between two adjacent rooms or between one room and the open air independently of the adjoining building elements. It is equivalent to ISO 140-10 and no current standard is superseded.

Amendments

BS 5724: Medical electrical equipment
Part 2: Particular requirements for safety.
Section 2.5: 1985 Specification for safety of ultrasonic therapy equipment. Amendment No. 1. This amendment effects the implementation of CENELEC HD 395.2.5.
BS 6655: 1986 Specification for pure tone air conduction threshold audiometry for hearing conservation purposes [ISO 6189: 1983]. Amendment No.1. This implements EN 26189: 1991 as a British Standard.
BS 6950: 1988 Specification for a standard reference zero for the calibration of pure tone bone conduction audiometers [ISO 7566: 1987]. Amendment No. 1. This implements EN 27566: 1991 as a British Standard.
BS 6951: 1988 Specification for threshold of hearing by air conduction as a function of age and sex for otologically normal persons [ISO 7029: 1984]. Amendment No. 1. This implements EN 27029: 1991 as a British Standard.
BS 7113: 1989 Specification for reference levels for narrow-band masking noise [ISO 8798: 1987]. Amendment No. 1. This implements EN 28798: 1991 as a British Standard.

British Standards Reviewed and Confirmed

BS 5942: High fidelity audio equipment and systems: minimum performance requirements.
Part 4: 1981 Specification for magnetic recording and reproducing equipment.
Part 6: 1980 Specification for amplifiers.
BS 2750: Measurement of sound insulation in buildings and of building elements.
Part 9: 1987 Method for laboratory measurement of room-to-room airborne sound insulation of a suspended ceiling with a plenum above it.
BS 3638: 1987 Method for measurement of sound absorption in a reverberation room.
BS 6086: 1981 Method of measurement of noise inside motor vehicles.
BS 6805: Statistical methods for determining and verifying stated noise emission values of machinery and equipment.
Part 1: 1987 Glossary or terms
Part 2: 1987 Method for determining and verifying stated values for individual machines.
Part 3: 1987 Method for determining and verifying stated values for batches of machines using a simple (transmission) method.
Part 4: 1987 Method for determining and verifying stated values for batches of machines.
BS 6812: Airborne noise emitted by earth moving

machinery.
Part 1: 1987 Method of measurement of exterior noise in a stationary test condition.
Part 2: 1987 Method of measurement at the operator's position in a stationary test condition.

British Standard Withdrawn

BS 880: 1950 Musical pitch. Obsolete.

New Work Started

BS 6328: Apparatus for connection to private circuits run by certain public telecommunication operators.
Part 1: Specification for apparatus for connection to speechband circuits. This will amend BS 6238: Part 1: 1985 to overcome difficulties in applying the longitudinal noise measurement tests set out in the standard.
Mechanical vibration – Guidelines for the measurement and assessment of human exposure to hand transmitted vibration (ISO 5349: 1986). This will implement ENV 25349.
BS EN 28662 Hand–held portable power tools – Measurement of vibrations at the handle. Part 1: General (ISO 8662–1: 1988). This will implement EN 28662–1.

European New Work Started

Household high fidelity audio equipment and systems – Methods of measurement:
Part 1: General. This will specify the general characteristics and their conditions and methods of measurement for household high fidelity audio equipment and systems.
Part 2: FM radio tuners. This will specify in conjunction with Part 1 of this standard, the characteristics and their conditions and methods of measurement for household high fidelity radio tuner units for reception of FM sound broadcasts with a rated maximum system deviation of +/- 75 kHz and using the pilot–tone system for stereophonic broadcasting.
Part 3: Amplifiers. This will specify in conjunction with Part 1 of this standard the characteristics and their conditions and methods of measurement of household high fidelity audio amplifiers of all types.
EN 255 Heat pump units with electrically driven compressors used for heating or heating and cooling:
Part 7: Heat pump units and heat pumps for heating sanitary water – Measurement of airborne noise – Determination of the sound power level (prEN 255–7). This will specify the requirements for determining, in accordance with a standardized procedure, the noise (parameter, sound power level) emitted into the surrounding air by heat pump units with electrically–driven compressors used for heating, heating and cooling, and for heating sanitary water.

International New Work Started

Earth–moving machinery – Machine mounted warning device – Ultrasonic or similar systems for slow moving machines. This will describe a method for evaluating the performance of the warning device, the minimum warning areas behind the machine, the optical and audible information to the operator and the self–monitoring properties of the system.
ISO 11957 Acoustics – Determination of sound insulation performance of cabins – Laboratory and in–situ measurements. This will give methods for determining sound insulation properties of sound–protecting cabins in terms of the reduction of sound pressure level using procedures in ISO 3741.
ISO 11342 Mechanical vibration – Methods and criteria for the mechanical balancing of flexible shafts. This will revise ISO 11342.
Sounders – Measurement and specification. This will specify the characteristics and their method of measurement for electroacoustic transducers for the radiation of simple or multiple tone signals for use in audio and video equipment, personal computers, communication terminals etc.

Draft British Standards for Public Comment

92/29392 DC Determination of transformer and reactor sound levels. (Possible new British Standard). [IEC 551: 1987 (modified)] (prEN 60551).
92/29554 DC Annex B to IEC 551 Determination of transformers and reactor sound levels (Possible new British Standard [IEC 14(Secretariat)190].
92/29555 DC Annex C to IEC 551 Determination of transformers and reactor sound levels (Possible new British Standard [IEC 14(Secretariat)194].
92/55018 DC BS 2750 Methods of measurement of sound insulation in buildings and building elements. Part 3: Laboratory measurements of airborne sound insulation of building elements (ISO/DIS 140–3 and prEN 20140–3).
92/31606 DC Amendment to IEC 268–5 Loudspeakers. Proposal for clause 24.10 [IEC84(Secretariat)252].
92/80264 DC Heat pumps – Heat pumps with electrically driven compressors – Part 7: Heat pump units and heat pumps for heating sanitary water – Measurement of airborne noise – Determination of the sound power level (prEN 255–7).
92/45097 DC Ergonomic assessment of speech communication – Part 1: Speech interference level and communication distances for persons with normal hearing capacity in direct communication. (ISO/DIS 9921–1).
92/45099 DC Ergonomics – System of danger and non danger signals with sound and light. (ISO/DIS 11429).

CEN European Standards

The following European Standards (ENs) have been approved by CEN.
EN 26189: 1991 Acoustics – Pure tone air conduction audiometry for hearing conservation purposes [ISO 6189: 1983]. Implemented as an amendment to BS 6655: 1986.
EN 27029: 1991 Acoustics – Threshold of hearing by air conduction as a function of age and sex for otologically normal persons [ISO 7029: 1984]. Implemented as an amendment to BS 6951: 1988.

EN 27566: 1991 Acoustics – Standard reference zero for the calibration of pure tone bone conduction audiometers [ISO 7566: 1987]. Implemented as an amendment to BS 6950: 1988.
EN 28798: 1991 Acoustics – Reference levels for narrow-band masking noise [ISO 8798: 1987]. Implemented as an amendment to BS 7113: 1989.
EN 29052: 1991 Acoustics – Determination of dynamic stiffness. Part 1: Materials used under floating floors in dwellings [ISO 9052-1: 1989]. Implemented as BS EN 29052-1: 1992.
EN 20140-10: 1992 Acoustics – Measurement of sound insulation in buildings and of building elements – Part 10: Laboratory measurement of airborne sound insulation of small building elements (ISO 140-10).

CENELEC Publications

HD 483 Sound system equipment
HD 483.3 S2: July 1992 Amplifiers
HD 483.17 S1 July 1992 Standard volume indicators

Approved Safety Standards

Consumer Protection Act 1987 Part II General safety requirement, The Approval of Safety Standard Regulations 1987 (SI 1987/1911); Regulations 2 and 3. Notice No.10.
The safety provisions of the following standard have been approved by the Secretary of State a standard of safety for the purposes of Section 10(3) of the Consumer Protection Act 1987:
BS 6344 Industrial hearing protectors
Part 1: 1989 Specification for ear muffs.

IEC Publications

IEC 1157: 1992 Requirements for the declaration of the acoustic output of medical diagnostic ultrasonic equipment.
IEC 1161: Ultrasonic power measurement in liquids in the frequency range 0.5MHz to 25MHz.

This information was provided by Miss Nicole Porter of NPL from the July to October editions of BSI News.

Book Review

Noise and Vibration Control Engineering: Principles and Applications L L Beranek and I L Ver (ed) Wiley -Interscience 1992. 804 pages. ISBN 0-471-61751-2 Cost £65.50

This book summarises a wide range of topics associated with noise and vibration control and has contributions from some distinguished engineers and acousticians such as Beranek himself, E E Ungar, Allan G Piersol and Theo Priede.

The stated aim of the book is to provide design engineers with specific technical information needed for solutions to the most frequently encountered noise and vibration problems. This is, perhaps, rather an unrealistic aim for a single book with such wide coverage. Some chapters do, indeed, provide directly useful design information but others do little more than give a brief summary of the subject and, instead, point the reader to other publications.

There are other chapters (for example, those concerned with the design of engines and the design of gears) which are interesting and informative, certainly, but hardly representative of 'frequently encountered' problems. In addition, there is a lack of editorial uniformity in the various chapters and the book gives a distinct impression of being twenty-one little books stapled together. To summarise, the book is not as balanced, elegant and useful as it might have been. However, there is much of it which is applicable and straightforward.

The subject matter is a more or less conventional assembly consisting in summary of the following topics in twenty-one chapters: Basic Acoustics, Data Analysis, Sound Power Levels and Directivity, Outdoor Propagation, Small Enclosures and Rooms (not clear why these merit separate chapters), Absorption, Structureborne sound *a la Cremer* (100 pages including six pages of references), Silencers and Ducts, Isolation, Damping, yet another chapter on Enclosures together with Wrappings, Gas Flows, Active Noise Control (in 20 pages), Human Factors, Machinery Noise, Engines, Electric Motors and Gears. However there is virtually no information on basic measurement techniques and on the uses and limitations of microphones. This is a serious omission.

The short chapter on Active Noise Control is welcome but much too short to be directly useful. It is a shame that there is not also a chapter on Active *Vibration* Control which is likely to have the wider application.

Also missing is a chapter on the practical diagnosis of noise and vibration problems (though there is an application-specific mention in the chapter on Electrical Machines). For some reason (is it the difficulty of the subject?) this seems to be omitted from almost all books on noise and vibration control.

As one might expect, the book has a strong US slant with frequent reference to various US standards and relatively little reference to ISO standards. This is particularly the case in the chapter concerned with noise assessment criteria. As a result some parts of the book have limited value to UK engineers.

However, it is commendable and surprising that SI units have been used more or less throughout. The quality of printing and presentation is satisfactory except in the case of some over-reduced reproductions of diagrams and charts.

Although there is much here that is useful, not much is new. The book is patchy. Some elementary topics get no mention, while some advanced topics get a relatively full treatment. Some sections are very interesting without being very useful while some other sections are really useful. With some regrets I cannot strongly recommend it for purchase.

A J Pretlove ❖

New Products

PULSAR

Sound Level Meters

These latest additions to the Pulsar range are designed to meet the needs of safety officers for use in compliance with noise at work regulations. Both meters meet IEC 804 and IEC 651 standards the Model 25 to Type 1 and Model 26 to Type 2.

The meters have an acquisition range from 45 dB to 143 dB. L_{eq} is displayed from 50 dB to 130 dB and True Peak from 70 dB to 140 dB both in three ranges. Sound Level (slow) can also be displayed. The meters are provided with 'A' and 'C' frequency weightings.

The meters are slim and rugged, housed in a die-cast metal case measuring 75 x 265 x 25 mm and weighing 460 g including batteries.

Further details from Pulsar Instruments Ltd, Bridlington Road Industrial Estate, Hunmanby, North Yorkshire YO14 0PH, Tel: 0723 891662 Fax: 0723 891742.

ALFRED PETERS

Audiometer Calibration Kit

Alfred Peters have introduced the CC182 Coupler incorporating its own condenser microphone. The CC182 is terminated in the 'Cirrus' L3M system connector and thus will connect to all European meters fitted with this interface.

In use, the earphone of the audiometer to be calibrated is simply placed on the 6 cc cavity of the CC182 and the CC182 plugged into the sound level meter.

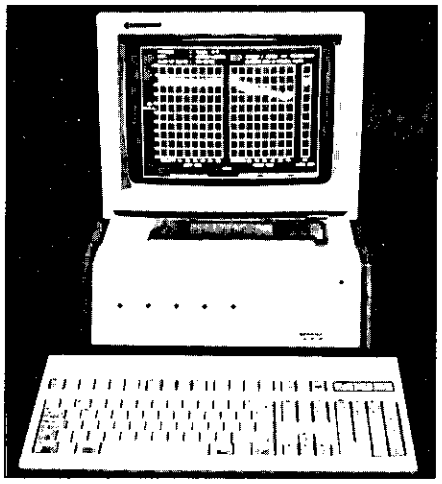
The tone levels of the audiometer can now be read directly on the sound level meter and corrected if required.

This procedure is simple and quick to perform as the CC182 does not need complex adjustments or mechanical setting up. It is complete and ready for use.

Each CC182 is complete with correction chart for the TDH 39 ear-phones which relates measurements to the International Standard IEC 645.

AP 250 Computer Controlled Screening Audiometer

The new Peters AP 250 Computer Controlled Screening Audiometer is purpose designed for large industrial screening programs. It conducts a conventional automatic audiogram and records the audiometric data whilst the test is in progress. On completion of the test, the individual's hearing is assessed against both the Health and Safety Executive's age norms for hearing loss and the individual's previous audio-



metric tests. This results in the individual's audiogram being automatically categorised saving valuable time for industrial medical staff and audiometric consultants.

The AP 250 satisfies class 4 of IEC 645. The AP250 has 8 test frequencies from 250 Hz to 8 kHz to cover both the IEC and OSHA requirements. Each frequency is continuously varied between -10 to +80 dB HTL at a rate of 5 dB per second in continuous or pulse tones, the latter being useful where the patient suffers from tinnitus. The user friendly Peters AP250 is designed to have minimal controls as all tests are controlled by a computer and the operational software has both on-line help files and an on-line manual. Further details from Alfred Peters Ltd., Industrial Estate, Hunmanby, North Yorks. YO14 0PH, Tel: 0723 890141. Fax: 0723 891742.

SOUNDSORBA

Absorbing Panels

Soundsorba acoustic products are highly effective in softening noise and reducing reverberation in offices, banks, schools, interview rooms, tele-conference rooms, recording studios and other environments. Soundsorba has a Noise Reduction Coefficient of 0.92 and is available in a wide range of colours. Standard panel size is 2700 x 1200 x 25 mm but custom built panels are available in almost any size. Soundsorba panels are available with hidden fixings or as a full clad system.

Soundsorba has recently been used to great effect in rest areas of Coca-Cola & Schweppes Beverages Limited busy telephone sales office. The problem consisted of noise distraction on the sales floor generated by people during their rest periods. Soundsorba Framed acoustic wall panels were used to absorb this unwanted noise and reduce reverberation in the rest areas. In addition, Soundsorba Free Standing Screens were strategically placed on the sales floor area to reduce noise transmission. For further information please contact Steve Parkinson, Soundsorba Ltd, The Business Unit, 28 Desborough Park Road, High Wycombe, Bucks HP12 3BQ. Tel: 0494 536888 Fax: 0494 536818.

SciTech

Analysis Using DIA-PC

SciTech has announced an upgrade to the original FFT analysis software module within the DIA-PC data acquisition package which now provides many of the features normally associated with dedicated FFT analyser or spectrum analyser instruments. The original software allowed the user to select any size of FFT transform and operate on any length of waveform. However, while this provides unlimited spectral resolution, many measurements suffer the effects of environmental noise and here the ability to average the data to obtain an improved signal-to-noise measurement is especially important.

The facility of ensemble averaging, to reduce the effects of random noise, has now been added to DIA-PC and can be performed throughout a complete measurement lasting minutes or even hours. Three types of averaging process are available: arithmetical, exponential and Peak Min. The user is then able to select the required FFT transform size and the number of channels. Overlap processing of the data blocks to be averaged is a new feature which can be used to obtain a greater number of averages within a finite time. Window functions provided include Hanning, Hamming, Exponential, Bartlett and a new facility for user-definable Windows. Measurement functions include: spectrum (FFT and inverse); auto- and cross power spectrum; transfer function; coherence; and auto and cross correlation. In addition, the Cepstrum, octave and third octave analysis function are now included.

Using the powerful graphical presentation capabilities provided by DIA-PC, the user can load standard layouts or create custom reports.

Further information is available from the exclusive UK suppliers: SciTech, 11 Ashton Road, Wokingham, Berkshire, RG11 1HL, Tel: 0734 772595 Fax: 0734 894007.

DYNAMIC ENGINEERING

FE Model Tuning Software

Dynamic Engineering have announced the latest version 3.1 of their SYSTUNE program for updating ('tuning') Finite Element models.

SYSTUNE correlates the vibration shapes and natural frequencies calculated by FEA with the results from Experimental Modal Analysis or from a second FE model.

Version 3.1 has many new features, including methods for weight reduction, identifying the complex properties of materials such as composites, planning vibration tests using the FE model.

SYSTUNE interfaces with industry-standard FEA and EMA programs and runs on engineering work stations and PCs.

Further details from Dynamic Engineering, Aizlewoods Mill, Nursery Street, Sheffield S3 8GG, Tel: 0742 823141 Fax: 0742 823150.

BRUEL & KJÆR (UK)

New Sound Level Analysers

Bruel & Kjær has introduced an entry-level portable analyser which not only brings the power of real-time frequency analysis to sound level meter applications but also allows new capabilities to be added as required via a cost-effective upgrade path.

In the new Type 2146 Sound Level Analyser, the powerful signal processing facilities developed for the Type 2143 real-time analyser are tailored to the applications and price range of the traditional sound level meter.

The 2146 employs parallel digital filter technology to cut measurement times to a fraction of those expected from an SLM and real-time operation allows measurement of the impulsive signals which are commonplace in the real world. The analyser includes a trigger multimode which allows spectra to be captured and stored at intervals between one milli-second and several hours.

This analyser, which is lightweight and battery powered, includes a PC-compatible disk drive permitting storage of data in the field for subsequent computer analysis.

The 2146 can be upgraded to include dual-channel operation (to use, for example, as a sound intensity analyser), FFT processing, charge amplifiers for vibration measurements and building acoustics software.

For further information contact Andrew Small, Bruel & Kjær (UK) Ltd, 92 Uxbridge Road, Harrow HA3 6BZ, Tel: 081 954 2366. Telex: 934150 BK UK G Fax: 081 954 9504.

Bruel & Kjær UK is a Key Sponsor of the Institute

CIRRUS RESEARCH

Wide Range Data Logging Integrating Sound Level Meter

The new Cirrus CRL 703A wide range data logging integrating sound level meter is the latest member of the CRL 700 family and has a user selectable range switch enabling the user to measure noise ranging from 30 to 130 dB(A) in two overlapping 70 dB dynamic spans. These two spans are both specified to fully comply with type 1 requirements of IEC 651, IEC 804, ANSI S1.23 and ANSI S1.4. The CRL 703A also has a parallel C weighted Peak channel for worker protection duties and this measures up to 140 dB(C).

The CRL 703A's keypad can be reprogrammed allowing the user to benefit from the meter's dual range by alternating between environmental monitoring and worker protection formats. This allows the user to choose keypad parameters that include L_{eq}, SEL, Dose, Exposure, Max, Min, L_1 and L_{95}.

The CRL 703A also provides an expanded memory to store up to 2,500 individual measurement events and 100,000 short L_{eq} elements. This stored data is fully compatible with Cirrus existing measurement software such as Acoustic Editor.

For further details contact Duncan Brown, Cirrus Research plc. Acoustic House, Bridlington Road, Hunmanby, North Yorkshire YO14 0PH, Tel: 0723 891655 Fax: 0723 891742.

Cirrus Research PLC is a Key Sponsor of the Institute

News Items

LUCAS CEL

Awarded BS5750

Lucas CEL Instruments of Hitchin announce that they have received BS5750 approval for their quality assurance management system.

To meet the standard, Lucas CEL had to undergo an assessment by an independent body, the National Inspection Council Quality Assurance. This involved a review of the company's entire quality management system that applies to all operations connected with the manufacture of the range of CEL noise measurement instruments.

On Monday 17th August the Member of Parliament for North Hertfordshire, Mr Oliver Heald, BS5750 certificate to Lucas CEL's Director and GM Ian Campbell.

After a conducted tour of the factory Mr Heald commented that 'BS5750 is part of a major Government initiative to raise standards in British industry. I was very impressed that an important group like Lucas should be making such an effort to reach International standard of industrial competitiveness via the 'quality' route and it is a tribute to all of the workers here. I know that a great deal of hard work has gone into achieving this accolade. It is an example that every business should follow.'

Lucas CEL Instruments is a Key Sponsor of the Institute

RION

Sound and Vibration Monitors For Hire

Concerned that essential monitoring under government legislation may be compromised by the high capital cost of instrumentation, Quantitech Limited, the environmental specialist, is now offering a hire service through its EnviroRENTAL Division. Included in the instrumentation available for hire are a range of state of the art sound and vibration monitoring instruments from RION of Japan.

The RION NA-29E, Real-time Octave Band Analyser and Precision Sound Level Meter is the ideal instrument for consultants and occupational hygienists.

This instrument is compact yet powerful, with five measurement modes over every measurement period and in each octave band, flat or A-weighted, and meets IEC Type 1 specifications.

The RION N14 Precision Integrating Sound Level Meter, with five measurement modes, five time constants, and weighing only 600 g, by using the latest advances in microprocessor techniques to combine a high capacity non-volatile memory with an RS232C interface, represents real portable power. The ideal instrument for Environmental Health Officers.

EnviroRENTAL is able to offer monitoring capabilities to suit every need. Where appropriate printers and calibrators are supplied at no extra cost.

For further information on hiring instruments, contact Andrew Green, Quantitech Ltd, Unit 3, Old Wolverton Road, Old Wolverton, Milton Keynes, Bucks, M12 5NP. Telephone 0908 227722.

HERAKLITH

New Product Catalogue, September 1992

A new brochure which catalogues the extensive range of Heraklith building boards and thermal and acoustic insulation products is available free from Atellus Limited of Maidenhead, sole UK agents and distributors.

The range includes the ecologically and biologically positive eraklith-M-Original magnesite bound wood wool building boards and robust Herakustic ceiling and wall panels.

These products, made entirely of natural materials, are formaldehyde-free and non-allergenic and are ideal for the design of 'breathing' structures.

Also included are details of the Heraklith-S wall sound insulation boards and the unique Tektalan-E-21 wood wool/mineral wool laminate board which is the basis of the impact resistant Tektalan-Facade exterior wall insulation system.

Reference to this new catalogue will show that there is are products in the Heraklith range to solve almost all thermal insulation and noise control problems.

For further information contact James Muir of Atellus Ltd, Park House, Marlow Road, Maidenhead, Berks SL6 6NR, Tel 0628 34563.

ALFRED PETERS

742 Audiometer Calibration Scheme

Alfred Peters Ltd, the original and sole manufacturer of 'Peters' audiometers, has recently introduced a more efficient service and recalibration scheme. This will prove highly beneficial to all users of 'Peters' audiometric and acoustic equipment who recognise the benefits of regular audiometric calibration.

Collection Service: A reputable carrier will collect and return your equipment.

Fixed Price Service and Recalibration: Labour and certain parts are included in this comprehensive package. Normal turn around is 7 days.

Emergency Repair Service: By prior arrangement only, this service offers a 24-hour turn round from receipt of equipment. Using the collection facility greatly increases the efficiency of this service.

Calibration to Standards Traceable to UK National Physical Laboratory: All instruments are tested to their full specification and calibrated to British Standards using Alfred Peter's rigorous test system.

For further information regarding how these various schemes can keep your 'Peters' audiometer at the peak of its performance and a breakdown of charges contact Pat Archer on (0723) 890141.

LUCAS CEL

New Catalogue Announced

The third edition of the Lucas CEL Instruments catalogue was published in September.

Produced in full colour, the six page publication provides information on CEL noise and vibration measurement equipment. The range includes sound level meters (Types 1 and 2), noise dosemeters, calibrators, analysers, software and allied equipment.

Two new products are featured in the new edition. The CEL-268 Environmental Noise Meter is the latest in CEL's range of Type 1 instruments and has been designed for the busy professional involved in the assessment of community noise nuisance or excessive sound levels generated by musical or sporting events.

With a software controlled keypad and microprocessor power the new hand held meter, say CEL, provides the means to collect, analyse and post process data on site.

A Building Acoustics system has also been announced. This is formed by connecting up to two applicable CEL sound level meters to the CEL-438 Noise Level Analyser. The program, which runs the system, is contained on a ROM card and is automatically installed into the analyser's memory by pushing the card into a slot on the instrument.

Typical measurement applications include reverberation time and decay rates.

The free catalogue can be obtained from: Lucas CEL Instruments Ltd., 35-37 Bury Mead Road, Hitchin, Herts SG5 1RT, Tel: 0462 422411 Fax: 0462 422511.

Lucas CEL Instruments is a Key Sponsor of the Institute

Items for the New Products section should be sent to John Sargent MIOA at BRE

Professor Teodors Priede

Professor Priede died on April 27, 1992, after a short illness, in George, Cape Province, South Africa, aged 71.

Born in Latvia in 1920, Professor Priede came to England after the Second World War. His first professional appointment was with British Internal Combustion Engine Research Association in Slough, Bucks, where he was persuaded to develop diesel engine noise research although his original intention was to pursue combustion research. From this chance start he laid the foundation of engine noise as he moved from BICERA to CAV and eventually to the Institute of Sound and Vibration Research at the University of Southampton where he built from scratch the Automotive Engineering Group.

Professor Priede's major contribution was his pioneering work in elucidating the fundamental mechanism of engine noise emission. He was recognised world-wide for his contributions and received many awards as well as being elected to be a fellow of the Fellowship of Engineering and Society of Automotive Engineers of US.

In 1984, he retired from ISVR and moved to Cape Town, South Africa to be close to his son and grandchildren; and at long last, enjoyed several years of fruitful research in knock in petrol engines at the University of Cape Town.

Apart from his technical achievements, Professor Priede was an accomplished musician; but he will be remembered most for his warm and cheerful personality as he was always ready to extend a helping hand to all who came in contact with him. He will be sadly missed by all who knew him.