Acoustics Australia

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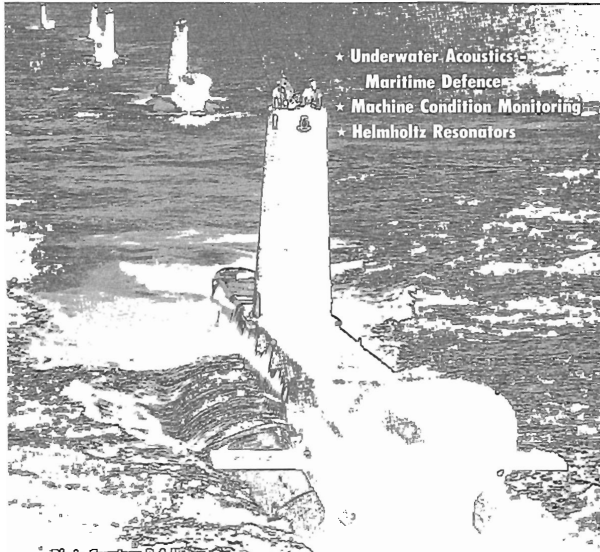

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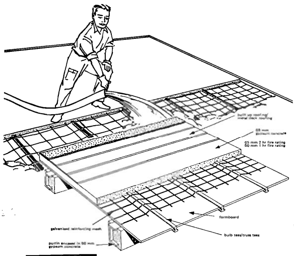

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NEWS

A.C.T.

First Meeting

On Tuesday, 24th February, 1987 **Louis Challis** spoke to almost 20 people who attended the first meeting of the Society to be held in the A.C.T. under the auspices of the N.S.W. Division. His talk was on the Acoustic Considerations of a Major Architectural Project with particular reference to the New Parliament House Project.

He outlined the general responsibilities of the acoustic consultant and the need for interaction with the others involved with the project. The new parliament house is a particularly complex project because of its large scale and the innovative design. Louis explained that the time restrictions led to his development of new computer aided techniques for rapid assessment of the acoustic environment within the large spaces for the House of Representatives and the Senate. The use of speech, which had been recorded in the models of the spaces, was of great benefit in demonstrating to the clients the need for more sound absorption and for careful placement of the reflecting surfaces.

The room acoustic considerations are not the only ones which are important in such a large project. Louis explained some of the other acoustic problems which had to be solved. His talk was followed by a lively question time before a dinner which was attended by half the audience.

Neville Fletcher was the Chairman for the meeting.

While there are only a few members of the Society currently resident in the A.C.T. there does seem to be a substantial interest in acoustics. It is therefore hoped that, if more activities are held in Canberra, more can be encouraged to join the Society and maybe a new Group of the Society can be formed.

N.S.W.

February Technical Meeting

The first meeting for 1987 was a joint meeting with the Institution of Engineers, on 18 February.

The topic for the meeting was the "Reduction of Noise from fans at Eraring Power Station". The two speakers were **A. Hanna,** a senior engineer from the Electricity Commission and **B. A. Russel,** the technical director from James Howden, Aust. The measurement procedures and reduction techniques for dealing with the noise from large low frequency sources were discussed.

From Queensland

Both **Warren Middleton** and **Peter Koorockin** have independently spent time recently in U.K. Warren has now returned to resume teaching duties at Q.I.T. while Peter is staying on to tour Europe.

The final meeting for 1986 was held at the Playground Theatre Restaurant and Cabaret. Approximately 14 members and friends partook of dinner and the show "Rise and Fall of the Roman Dictator".

Notes from the Gen. Sec.

1988 Annual Conference . . . the South Australian Division Committee has accepted responsibility for organising and running the 1988 Annual Conference. No dates or themes have been finalised at this stage but it is expected that it will probably be organised for the latter half of the year.

* * *

National Committee on Physics . . . in recent years the National Committee has taken a special interest in acoustics and in so doing has initiated and sponsored a scientific meeting on Underwater Sound and supported our successful nomination for the Commission on Acoustics. There have been initiatives in other areas including optics.

The initial AAS representative on the National Committee on Physics was Paul Dubout and subsequently Ray Piesse. The representation has continued for about 10 years. The Council of the AAS has now nominated Dr. **Neville Fletcher** to serve on this committee until May 1989. Neville Fletcher has a long-time interest in acoustics and is at present Director of CSIRO Institute of Physical Sciences in Canberra.

* * *

Engineering Award . . . noted in Consulting Engineer for September 1986 among the annual ACEA Engineering Awards, an award of High Commendation for Louis Challis & Associates for their project 'Observation Booth for testing FA18A Hornet Aircraft — Victoria.

FASTS Request

(FASTS is the Federation of Australian Scientific and Technological Societies of which the Australian Acoustical Society is a member.)

"FASTS is entering into an arrangement with the airlines to promote FASTS Member Society 1988 Conferences overseas. Where people can link a few Conferences together they are more likely to travel overseas.

If you would like your 1988 Conference to be promoted in this way please send in whatever details you can.

We will be looking at some initial promotion in April 1987. Dates and venues would be appreciated, draft programs if you have them."

G.P.O. Box 2181, Canberra, A.C.T. 2601. Tel.: (062) 47 3554.

Bruel & Kjaer Move

The telephone number given in our last issue was not correct. Bruel & Kjaer's new address is 24 Tepko Road, Terrey Hills 2084; postal address is P.O. Box 177, Terrey Hills 2084; telephone **(02) 450 2066;** telex AA 26246.

Mini-Editorial

In this issue there is evidence of a little editorial tidying-up. The previous sections Australian News, International News and People have been amalgamated into one section simply called News. In these days of satellites, desk computers, modems, FAX machines, etc. it does not seem to matter where the news originates — it gets around faster than ever.

Speaking of FAX machines, authors and suppliers of any written material, especially late material (late in the sense that it is long past the editor's deadline but the printer is still poised with his finger on the GO button) may now send their contributions directly using FAX No. **(02) 523 2163.** This will deposit your exemplary prose in the office of Cronulla Secretarial Services to be processed immediately, if not sooner, by **Sandy Eastman** who is now in charge of all our administrative and advertising business. For all business matters please call Sandy on **(02) 527 3173.**

The editorial committee is grateful to Jane Raines for her work as Advertising Manager prior to her recent retirement from that position.

Howard Pollard
Chief Editor

Australian Acoustical Society Records

Council at its 37th meeting decided to implement a centralised computer based record for every member to increase the effectiveness of its administration and reduce the work load of some of its voluntary office bearers.

The records which will include details of membership, subscription payments, members interests and addresses will be maintained by the Science Centre Foundation in Sydney. They will be suitable for keeping the Society's Registers of members up to date, compiling the Society's Directory and for mailing purposes.

The annual subscription notice which in future will be issued by the Science Centre Foundation will be designed to give members an opportunity to amend their records, particularly their addresses and interests.

Letter to the Editor

Dear Sir,

Following a workshop session at the 1986 A.A.S. Conference in Toowoomba concerning annoyance caused by noise, I undertook to list the numerous factors which the meeting raised in relation to this very complex field of study and forward it to you in the hope that —

(a) you would consider it for publication;
(b) it may stimulate research into some of these areas;
(c) others may be able to add to the list.

The list, not necessarily in order of importance, is:—

Physical Factors

(1) Level of sound and its variability.
(2) Frequency spectral content (broad-band, tones, doppler effect, etc.).
(3) Intermittency (irregular or cyclic onset and decay rates).
(4) Sound propagation (wind and temperature gradients).
(5) Surface effects (ground cover, intervening contours, rates of change of contours).
(6) Background noise in relation to the noise causing annoyance.
(7) Shock or vibration associated with the noise.
(8) Resonance within spaces where annoyance occurs.

Psychological Factors

(1) Unpredictability of noise occurrence or characteristics.
(2) Familiarity once annoyance is established.
(3) Tones, hisses, screeches and low-frequency rumbles.
(4) Identication with the noise source (occupational, etc.).
(5) Stress from other causes (insomnia, illness, domestic upsets).
(6) Expectations when moving-in.
(7) Ease for registering complaints.
(8) Activity disturbance (speech, telephone, TV viewing, radio, hi-fi, concentration, relaxation and sleep).
(9) Combination of visual and aural disturbance (headlights / traffic, factory nightshift, etc.).
(10) Sociological status.
(11) Desirable sound to one (music), anathema to another (noise).
(12) Inability to affect source of noise.
(13) Hearing characteristics of individuals.
(14) Age and gender of listeners.

A further suggestion was that annoyance may be affected by whether the listener was prone or upright but this seemed to be a conjecture only.

J. A. Rose (Principal)
J. A. ROSE ACOUSTICS

* * *

The Editor will be pleased to receive your comments or thoughts on Jack Rose's letter.

VIPAC Award

A Vipac invention called 'DIDEMS' has won the Victorian Enterprise Workshop Patron's Award. A prize of $10,000 was awarded towards the commercialisation of the product.

The prize money for the award comes from the Department of Industry, Technology and Resources.

* * *

DIDEMS (The Digital Interactive Diesel Engine Monitoring System) is the first comprehensive diesel engine diagnostic system in the world. The system developed by Vipac, employs sophisticated signal gathering technology and advanced signal processing methods to produce an extremely powerful diagnostic system. It is the only "strap on" system available and can be easily dismounted after the diagnosis has been completed.

In Vipac's development laboratory, 43 different operating condition defects were detected by DIDEMS on a single test engine. The device can improve the efficiency of the diesel engine through fine tuning. It can also save a great amount of time for engine inspectors — inspection of faulty engines usually takes up to 16 hours — with DIDEMS it only takes 10 minutes. A good insight into the faults of the engine is gained at the same time.

The workshop team selecting it, made a thorough examination of the world market and confirmed Vipac's optimism for the project. It can help the economy in saving thousands of dollars each day by improving engine efficiency.

Bruel & Kjaer Opening

The official inauguration of the new Australian headquarters of **Bruel & Kjaer Australia** was held on February 5, 1987 by Uffe Elleman-Jensen, the Danish Minister for Foreign Affairs. Dr. P. Bruel and Dr. V. Kjaer, the founders of the parent company were present as were the Federal Member, Jim Carlton and the State Member Jim Longley.

In his introductory talk, **Cliff Winters** explained how the building was designed to fit in with the surrounding residences and, whilst not intentional, does reflect some Scandinavian association. The new premises incorporate larger storage facilities, expanded service capabilities, a lecture room for

The new headquarters building of Bruel & Kjaer Australia.

customer back-up training as well as office facilities. There is also the option for future expansion.

Over 200 guests from around Australia were present for the opening. All enjoyed the refreshments, luncheon and the opportunity to chat with friends and colleagues from the acoustics field.

The new address for B & K is 24 Tepko Road, Terrey Hills, N.S.W. 2084. (02) 450 2066.

Standards

Noise Levels for Rotating Electrical Machines

AS 1359.51 — Noise Level Limits, specifies revised noise level limits in terms of sound power levels for rotating electrical machines from 1 kW (or kV.A) to 5500 kW (or kV.A) using methods of measurement in accordance with the latest ISO engineering method (ISO 1680/1) rather than the ISO survey method (ISO 1680/2).

This new edition explains the difference between the two methods, and gives the reasons for the specified choice. It does not consider the legal aspects of noise pollution but recognises achievable noise levels of machines of standard design and availability of supplementary means of noise attenuation where necessary. Guidance in the calculation of mean sound pressure levels at various distances from a machine is provided in an appendix.

Noise Levels and Reverberation Times in Buildings

AS 2107 has been widely used since its first publication in 1977 and this new edition incorporates certain changes to clarify some of its previous provisions. The table of recommended design levels has been expanded to cover additional types of occupancy/ activity, and recommended reverberation times have been added.

The 1987 revised version is entitled "Recommended Design Sound Levels and Reverberation Times for Building Interiors" and is intended to assist designers to provide a certain acoustic environment within occupied spaces in new and existing buildings. It is also intended for the application in the selection and assessment of building materials and services used in these spaces.

* * *

Recent Activities of Acoustics/Vibration Committees

- One of the major events in the area of Acoustics and Vibration for the year just passed was the amalgamation of the two areas of work under a common board (AV/-). SAA Council endorsed the constitution of the **Acoustics/ Vibration Standards Board** late in 1985. The Council supported the proposal as significant and interrelated growth between the two areas was foreseen, especially in the environmental area of noise and vibration measuring and control.
- One of the recent major publications was the revision of **AS 2021**, Acoustics, Aircraft Noise Intrusion — Building Siting and Construction. The revised standard incorporates actual noise measurements for landings and take-offs of the new generation of wide-body aircraft operating at the major airports throughout Australia. A new method of exposure forecast, unique to Australia, was included in the revised standard.

• Other major standards published were the revision of **AS 1191,** Acoustics, Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Transmission, the new revision in seven parts of **AS 1217,** Acoustics — Determination of Sound Power Levels of Noise Sources. The revised and expanded version of **AS 1633,** Acoustics, Glossary of Terms and Related Symbols, and the new standard **AS 2822** Acoustics, Method of Assessing and Predicting Speech Privacy and Speech Intelligibility. In 1987 the revised version of **AS 2107,** Recommended Design, Sound Levels and Reverberation Times for Building Interiors, was published.

• In the Vibration and Shock area, the following new standards were published; **AS 2625.4,** Measurement and Evaluation of Vibration Severity of Small Rotating Machines. **AS 2763** Vibration and Shock — Hand Transmitted Vibration — Measurement and Medical Screening; and **AS 2775,** Vibration and Shock — Mechanical Mounting of Accelerometers.

• A fairly large amount of new work was undertaken by the newly constituted board. The most relevant projects in the acoustics area are:

1. Siting and Construction Relative to Traffic Noise (this project is the responsibility of sub-committee AV/5/3).
2. Revision of three standards (AS 1948, 1949 and 2254) dealing with methods of measurement of noise aboard vessels, recommended noise ratings for various areas of occupancy in vessels, and method of measurement of noise emitted by vessels in ports and harbours. The standards covering noise emitted and aboard ships has been extended to cover off-shore platforms. (Committee AV/3/4 and AV/5/5).
3. Preparation of a new series of standards dealing with noise emitted by household appliances. (AV/7).
4. A new standard dealing with the method of noise measurement of lawn mowers, brush cutters and edge cutters. (AV/6/1).
5. Revision of AS 1270, Hearing Protection Devices and AS 1269, Hearing Conservation. (Sub-committee AV/3/2 and AV/3/1 respectively).
6. Preliminary investigations for standards dealing with rain noise on metal roofs, helicopter noise, and impact noise on floors and walls are being carried out. (AV/5).

• In the area of Vibration and Shock, the following projects have been started:

1. A new standard dealing with the specification of vibration isolators. (AV/9).
2. A new standard dealing with the driving point impedance of the human body. (AV/10).
3. A new standard dealing with the human body response vibration measuring instrumentation. (AV/8).

M. MAFFUCCI
Standards Association of Australia

Conference Information

The Australian Academy of Science has decided not to continue producing the **Calendar of National and International Conferences in Australia.** As an alternative, information is available on the **Australian Conferences** database via the **CSIRO Australis** information retrieval service.

Australian Conferences is an authoritative list of conferences being held in Australia, Australian conferences being held overseas and significant international conferences being held in the Asian-Pacific region. At present the database contains mainly scientific and technical conferences but it will expand to cover other areas.

The database is produced by the CSIRO Information Resources Unit and is based on the wide range of information on science and technology which is processed by this unit. Conferences are listed in some detail. As conference arrangements progress and more information becomes available, the conference listing is updated. Conferences are left on the database after the conference date to assist in tracking down the published Proceedings.

CSIRO Australis is an on-line information retrieval service available throughout Australia. The service is currently designed for librarians and information officers but can be used by anyone who is prepared to learn how to use the service. A manual is available to assist users and user support is available in each capital city.

Further information: CSIRO Information Resources Unit, P.O. Box 89, East Melbourne, Vic. 3002. (03) 418 7333.

Inter-noise 87

VENUE . . . The Conference will be held at Beijing Science Hall from September 15 to September 17, 1987. Beijing Science Hall is within the yard of the Friendship Hotel which is located in the north-west suburb of Beijing. All the session meetings of this Conference and the technical exhibition will be held there.

REGISTRATION . . . For Conference Participants the registration fee is U.S.$150. For Students enrolled in degree program, the registration fee is U.S.$75. These fees will cover the following items: one set of Conference Proceedings (English or Chinese), attendance at all sessions and exhibits, three lunches, refreshments during the sessions, and transportation from and to the airport. Additional set of Proceedings is available at pre-publication price of U.S.$25.

For accompanying persons the registration fee is U.S.$50 which will cover three lunches, the city tours BT-1 and transportation from and to the airport.

Participants are advised to make reservations and prepayment for the anticipated number of nights before 15 July, 1987, otherwise accommodation cannot be guaranteed.

For further details contact your Division Secretary (for addresses see back cover).

New Members

• Admissions

We have pleasure in welcoming the following who have been admitted to the grade of Subscriber while awaiting grading by the Council Standing Committee on Membership.

New South Wales
Mrs. U. B. Mizia.

Victoria
Dr. C. G. Don, Mrs. J. C. Evans, Mr. M. J. Snell.

• Graded

We welcome the following new members whose gradings have now been approved.

Student
New South Wales
Mr. J. F. Hayes.

Subscriber
New South Wales
Mr. B. R. Cremin.
Victoria
Mr. S. Leverton.

Member
South Australia
Mr. P. J. Maddern.

Victorian Technology Centre

A joint industry/government initiative has been established in the Port Melbourne region, an area dotted with technologically oriented businesses, to aid Australian manufacturers seeking a sound technology basis from which to develop new products and services for both domestic and export markets.

The **Victorian Technology Centre** offers a co-ordinated approach to obtaining contracts for major government and private enterprise, offset and export projects. The Centre acts as a marriage-broker linking all the elements necessary for a successful project — the expertise and interactive skills of engineers and scientists from industry, government agencies, and academic institutions. **Mr David Sanderson** is the Victorian Technology Centre's Chief Executive Officer.

The Centre is setting up a national information network to identify potential projects well before the 'request for tender' (RFT) stage. The Victorian Technology Centre will act as a single point of contact and will seek to establish solid relationships with potential clients so that Australian industry will be in a position to become involved at concept stage and will be able to respond quickly to tender requests and opportunities.

The Victorian Technology Centre was established by **Vipac Pty. Ltd.,** an applied research and consultant engineering company, in 1983. The Centre is supported by the Victorian Department of Industry, Technology and Resources, the Australian Chamber of Manufacturers and the firm of chartered accountants, Nelson Wheeler.

Membership of the VTC is open to all areas of Victoria and Australian industry.

For further details contact the Victorian Technology Centre, 275-285 Normanby Road, Port Melbourne 3207. (03) 645 2144.

U.K. Noise Council

Ever since the demise of the Noise Advisory Council in the U.K. (it was axed six years ago as an unwanted Quango) a group within the Institute of Acoustics had been seeking the best way to establish an alternative body.

In March 1986 the Noise Council was launched at a reception in the House of Lords hosted by Lord Nathan. The aims and objectives of the Noise Council are to promote and respond to issues relating to noise and vibration and to make independent technical and scientific expertise available to international and national agencies, central and local government, commerce and industry.

The members of the Council include Lord Elliott of Morpeth as Chairman, Roy Emerson and Geoff Leventhall as Deputy Chairmen and Ian Acton, Peter Anderson, Mike Ankers, Richard Atherton, Don Barnett, Graham Jukes, John Large, Peter Lord, Ernie Scholes and John Stirling as members.

The first activity of the Council has been the production of a publication **"Noise Legislation — Its Effectiveness for Noise Control"**. This well-referenced 16-page document (available from Noise Council, Chadwick House, 48 Rushworth Street, London SEI OQT for £1.00) discusses legislation which has worked well and identifies a wide range of areas in which there have been problems.

Future activities of the Noise Council include consideration of regulations on occupational noise exposure, in order to present a unified view for consideration by the Health and Safety Commission. The Council has made a promising start and, with continuing support from its founding bodies, looks set to become a major force in determining U.K. policy on noise.

(Extracted from I-INCE Newsletter No. 43)

1987 Annual Subscriptions

The following motions were passed at the 16th Annual General Meeting of the Society held on 2 October, 1986.

(1) That as from, and including, 1st April, 1987 Annual Subscription rates will be — Members $50, Affiliates $40, Subscribers $40, Students $30.

(2) That commencing with Annual Subscriptions due on 1st April, 1988 Council may, if it considers it necessary and without the need to obtain membership approval at successive Annual General Meetings, index subscription rates by a percentage not exceeding the percentage change in the National (weighted average of eight capital cities) Consumer Price Index for the preceding fiscal year.

Bicentenary Congress of Physicists

25-29 January 1988
University of New South Wales

The Congress is a concentration of specialist meetings with the program structured around strong contributions from working scientists. A limited number of plenary lectures will be presented by eminent scientists, including Nobel Prize winners, selected by the specialist groups.

The Australian Acoustical Society is supporting the Congress and will be organising one of the sessions devoted to Seismic and Underwater Acoustics.

Further enquiries: Dr. S. J. Collcott, C.S.I.R.O. Division of Applied Physics, P.O. Box 218, Lindfield 2070. Tel.: (02) 467 6211.

Appointment

Dr. Andrew Hede has recently been appointed director of the Public Policy Research Centre. Andrew was formerly head of Socio-Acoustics Research at the National Acoustic Laboratories and head of Noise Control at the Victorian Environment Protection Authority. The Public Policy Research Centre is a division of Yann Campbell Hoare Wheeler, and is the only private consultancy specialising in social as distinct from marketing research. Anyone interested in social surveys can contact Andrew on (02) 922 3344.

Machine Condition Monitoring Using Vibration Analyses

J. Mathew
Department of Mechanical Engineering
Monash University
Clayton Vic. 3168

ABSTRACT: Machine condition monitoring is concerned with obtaining data which would aid in evaluating machinery mechanical integrity. Various techniques have been developed in recent times and these can be broadly classified into six categories: aural, visual, operational variables, temperature, wear debris and vibration monitoring. This article is mainly concerned with the last of these, vibration monitoring. The various forms of vibration analysis techniques applicable to machine condition monitoring techniques are described. It is shown that relying entirely on any one technique may be unwise. It would be preferable to process the basic time domain signal in several ways to highlight different aspects of the signal which would in turn relate to different failure modes. The evidence obtained from vibration monitoring can finally be integrated with data obtained using other techniques to confidently identify machinery failure.
KEYWORDS: Condition monitoring, vibration monitoring, vibration analysis, time domain, frequency domain, quefrency domain.

1. INTRODUCTION

It is generally accepted that preventative maintenance can adopt one of three different approaches. Breakdown maintenance is practised when machines are operated until they fail before maintenance techniques are scheduled. Scheduled maintenance is concerned with interrupting the machines at regular intervals for maintenance, in order to reduce the number of unplanned stoppages that can arise as a result of a breakdown maintenance strategy. However, the selection of an optimum maintenance interval is a difficult task in many situations. Too frequent maintenance can be a waste of resources as well as valuable production time. It may also increase the risk of damage to machinery that may arise from human errors during reassembly. On the other hand, too long an interval would result in more failures than desired. A more acceptable maintenance policy would be to determine the maintenance interval by monitoring the actual condition of machines. This latter approach would certainly result in increased plant availability which would in turn result in greater return from the capital invested. Other benefits include reduced maintenance costs and improved safety, particularly in machinery where failure constitutes a health or physical hazard.

The clear advantages offered by the application of the "on condition" approach has in recent times led to the development of a vast number of techniques for monitoring machinery condition [1, 2]. These can be broadly classified under the categories described in Figure 1.

Aural and visual monitoring techniques are considered to be basic forms of monitoring machine condition. It is commonly accepted that skilled personnel who have intimate knowledge of machines, are capable of identifying failure occurring by simply listening to the sounds of distress emitted by nearby machines. There are those who indeed have enhanced their skills by being able to *listen* to machine vibrations. The method consists of placing a spanner or rod against the machine and their earmuffs. An extension to this method is the stethoscope. These range from simple rod cum tube to earpiece devices, to those that pick up the rod or tube vibrations using a microphone. The signal obtained from the microphone can be either amplified or filtered before being fed to a headset [3].

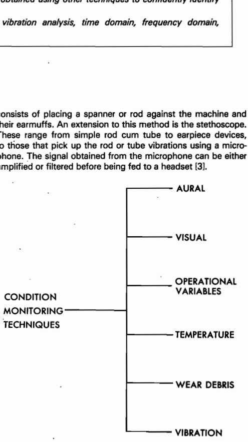

Figure 1: Condition monitoring techniques

Visual monitoring can sometimes also provide a direct indication of the machine condition without the need for further analysis. Techniques range from using simple magnifying glasses or low power microscopes to light assisted devices such as boroscopes and stroboscopes [4]. Other forms of visual monitoring include using dye penetrants to provide a clearer definition of cracks occurring on the machine surface and the use of heat sensitive paints also known as thermographic paints. Usually these paints need to be selected to match the temperatures to be measured which would involve some prior knowledge of the likely surface temperatures.

The monitoring of the operational variables in machinery is sometimes also known as performance or duty cycle monitoring [5]. The objective of this technique is to gauge each machine's performance to its intended duty. Any major deviations from expected or design values indicate the existence of a problem which usually relate to machine malfunction. However, in many machines, monitoring its operating variables tends to be less sensitive than other methods in detecting incipient or early failure. Quite often the failure in machine elements has to be well advanced before a measurable change is produced in its operational variables.

Temperature monitoring consists of measurements of the operational temperature and the temperature of component surfaces [6]. The monitoring of operational temperature can be considered as a subset of the operational variables discussed previously. The monitoring of component surface temperatures has been found to relate to wear occurring in machine elements particularly in journal bearings where lubrication was either inadequate or absent [7]. Techniques for monitoring temperature of machine components include the use of optical pyrometers, thermocouples, thermography and resistance thermometers.

Wear debris is generated at relative moving surfaces of load bearing machine elements. Hence it is possible to assess the condition of these surfaces if the wear debris were collected and analysed. The various techniques currently being employed or being researched [8] are summarised in Figure 2. A discussion of each of these techniques is beyond the scope of this article. However, it is important to acknowledge the existence of these techniques. They can be used successfully in addition to, say, vibration techniques, to provide corroborative evidence of machinery failures [9, 10].

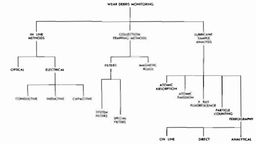

Figure 2: Wear debris analysis techniques

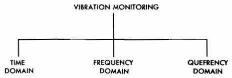

Figure 3: Vibration monitoring techniques

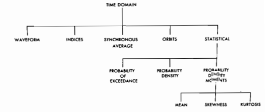

Figure 4: Time domain analysis

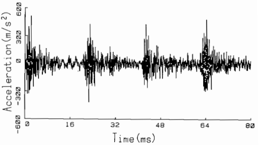

Figure 5: Time domain waveform of a damaged gear

Machine vibrations arise from cyclic excitation forces within the machine. These forces are sometimes built into the design of the machine or can be due to real changes in dynamic properties of individual machine elements due to wear or failure. These excitation forces are transmitted to adjacent components or adjoining structure, causing parts of the machine remote from the source to vibrate accordingly to varying degrees.

The measurement of machine vibration can be made using a wide array of transducers [11], and these will not be discussed here. However it would suffice to mention that the piezoelectric accelerometer is probably the most popular measurement transducer in use today, due to its wide frequency and dynamic range. The acceleration signals obtained from these transducers are sometimes integrated to produce velocity or even displacement for different applications. These signals are then processed in different ways to highlight different aspects of the signal which can then be used in the detection and diagnosis of the machine condition. The various techniques can be broadly classified under the categories shown in Figure 3.

2. THE TIME DOMAIN

Time domain signals if understood properly, can yield enormous amounts of information. Further analysis is usually carried out so that some characteristics not readily observed visually, are highlighted. Several techniques have either been proposed or used in machine monitoring and they are shown in Figure 4.

2.1 Waveform Analysis

This technique consists of recording the time history of the event on a storage oscilloscope or a real time analyser. Apart from an obvious fundamental appreciation of the signal, such as if the signal was sinusoidal or random, it is particularly useful in the study of non-steady conditions and short transient impulses. Discrete damage occurring in gears and bearings such as broken teeth on the former and cracks in the inner and outer races of the latter, can be identified relatively easily [12]. An example is shown in Figure 5, where the waveform of the casing vibration acceleration of a single stage gearbox with a broken tooth on the pinion is presented. The pinion in this example was directly coupled to a 5.6 kW, 2865 rpm AC electric motor. Under nominal load, a shaft speed of approximately 3000 rpm was obtained. Hence a single discrete fault on the pinion such as the broken tooth would produce pulses in the time domain with a period of occurrence of 20 ms or so. This feature is clearly evident in Figure 5. Waveform analysis can also be useful in identifying beats and vibrations that are non-synchronous with shaft speeds. In machine coast down analysis, waveforms can indicate the occurrence of resonances [13].

2.2 Indices

The Peak level, RMS level and their ratio Crest factor, are often used to quantify the time signal. The Peak level is not a statistical quantity and hence may not be reliable in detecting damage in continously operating systems. The RMS value, however, would be more satisfactory for steady state applications. Even so, the value of either of these parameters tend to be governed by the amplitude of large components occurring in the time signal. Hence, unreliable data would be obtained when monitoring machinery where the time signal contains information pertaining to more than one element, say a multistage gearbox where the time signal would contain information from the high and low speed gears as well as the bearings.

The Crest factor, defined as the ratio of the Peak to RMS levels, has been proposed as a trending parameter as it includes both parameters [14]. However, investigations by the author have shown that this parameter usually increases marginally with incipient failure and subsequently decreases due to the gradually increasing RMS value typical of progressive failure. Quite often, the trend recorded by this parameter has been found to be similar to another time domain parameter, the Kurtosis factor. Evidence of this similarity will be produced later when the Kurtosis factor is discussed.

2.3 Time Synchronous Average

Synchronous averaging is the time signal averaged over a large number of cycles, synchronous with the running speed of the machine. This technique not only removes background noise but also periodic events not exactly synchronous with the machine being monitored. It is especially useful in gear vibration diagnosis where multiple shafts are present. All components not synchronous with the shaft of interest can be deleted. A typical measurement setup would consist of the transducer usually an accelerometer, a tachometer which would produce the reference pulse and a signal averager. Signals of shafts not synchronous with the reference shaft can also be averaged if the repetitive rate of the reference pulses are altered with the aid of a pulse frequency multiplier [15].

2.4 Shaft Orbits

Lissajous patterns are obtained by displaying time waveforms obtained from two transducers whose outputs are phase shifted by 90 degrees, on an oscilloscope where the time base is substituted with the signal from one of the probes. When shaft relative displacement probes are used, the pattern so obtained is the shaft orbit and can be used to indicate journal bearing wear, shaft misalignment, shaft unbalance, lubrication instabilities in hydrodynamic bearings and shaft rub [13]. The techniques of proximity analysis are well established, particularly with applications to turbomachinery. Eddy current tranducers are commonly used in addition to appropriate signal conditioners. However, care needs to be exercised when mounting these eddy current devices, so that the effects of mechanical and electrical runout are minimised [16]. Otherwise, spurious signals will be obtained during measurements. An example of orbit analysis used in monitoring journal bearing wear is presented in Figure 6. Two eddy current proximity probes were placed at 90 degrees radially along the shaft.

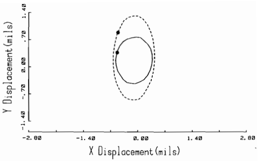

Figure 6: Orbit monitoring;
——— Baseline orbit, – – – Orbit with worn bearings

Mechanical glitch was minimised by accurate machining of the target area of the probes. Electrical glitch was minimised by pushing an aluminium sleeve onto the target area. In this particular test, the bearing inner diameter was deliberately enlarged by boring out bearing material. The results clearly showed that the orbit diameter increased particularly in the vertical direction, indicating that this rotor bearing system was stiffer in the horizontal direction. Hence the added bearing clearance due to the simulated wear condition resulted in larger vertical relative displacements.

2.5 Statistical Analysis

2.5.1 Probability Density

The probability density is the probability of finding instantaneous amplitude values within a certain amplitude interval, divided by the size of the interval. All signals will have a characteristic probability density curve shape. These curves if derived from machinery vibration signals can subsequently be used in monitoring machine condition. Examples of the application of this parameter to rolling element bearing monitoring are already available [12, 14, 17]. A further example of damage detection in a high speed rolling element bearing is shown in Figure 7. Damage was induced by producing a small radial groove on the outer race of the bearing. This action resulted in the vibration acceleration waveform looking not unlike Figure 5. The waveform when the bearing was in good condition was characteristic of a random waveform with a probability density curve that was similar to the normal distribution or bell shaped curve. Note that the expression of the vertical axis in the logarithmic scale tends to produce a distorted shape when compared with probability curves expressed in linear scales. This is deliberately carried out to

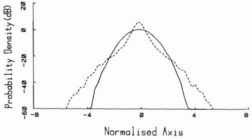

Figure 7: The probability distribution of bearing vibration acceleration amplitude. ——— baseline data, – – – damaged bearing

highlight changes at low probabilities if and when they do occur. The horizontal axis is the vibration acceleration signal normalised to the standard deviation. The probability density curve for the damaged bearing when compared with the curve for the good bearing is seen to be significantly different in shape. The high levels of probability density at the median and the large spread at low probabilities are characteristics of highly impulsive time domain waveforms. The probability density technique is useful in the *diagnosis* of machine condition as it is based on comparisons of shape variations rather than the amplitude variations.

Probability density curves can also be trended like any other trending parameter if the data can be presented in the form of *waterfall or cascade* diagrams. For example, Figure 8 shows the effects of shaft rubs on the housing acceleration of a journal bearing. Baseline curves shown earlier in the cascade diagram clearly undergo distinct alterations in both shape and amplitude, indicating a malfunction of some sort. Presentation of data in this form can readily provide a large portion of the required information for condition monitoring quickly.

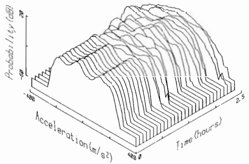

Figure 8: A probability density cascade diagram

2.5.2 *Probability of Exceedance*

The probability of exceedance has also been used in monitoring bearing condition [17]. It is the integral of the probability density curve and gives the probability that the instantaneous vibration amplitude exceeds any particular amplitude. Again, these curves can be monitored to provide an indication of bearing failure.

2.5.3 *Probability Density Moments*

The shape of the probability density curve can be described by a series of single number indices. These are moments of the curve and analogous to mechanical moments about the centroid axis of a plane. The first and second of these moments are well known, the mean and mean square. Odd moments relate information about the position of the peak density relative to the median value. Even moments indicate the spread in distribution. Usually moments greater than two are normalised by removing the mean and dividing by the standard deviation raised to the order of the moment. The third moment is Skewness and the fourth is Kurtosis. For practical signals the odd moments are usually close to zero whereas the higher even moments are sensitive to impulsiveness in the signal. Kurtosis has been selected as a compromise measure between the insensitive lower moments and the over-sensitive higher moments. This parameter has been proposed to be sensitive to failure in rolling element bearings [17]. However, an independent evaluation of this technique [18] has shown that high Kurtosis values would only be obtained if the original time waveform was of an impulsive nature. This characteristic does arise in some forms of failure in bearings such as cracked races. Spalls occurring in the edges of the rolling elements of barrel or spherical roller bearings can also cause relatively large pulses in the time domain waveform. When applied to the previous example of a bearing where the outer race was damaged, the trend of the Kurtosis factor is shown in Figure 9. The Crest factor trends are also shown in this figure. Both of these parameters produced values of approximately three which indicated that the waveform was generally random in nature when the bearing was in good condition. Trends changed dramatically especially for the Kurtosis factor when damage was introduced. A Peak value of 13 or so was attained by the Kurtosis parameter signfiying that the shape of the probability density curve had changed appreciably. Progression of the damage did not show continued increases. Instead the converse was true, indicating that the impulsive content in the waveform gradually decreased. It is acknowledged, though, that in this particular example, trend increases were recorded towards the termination of the test. Tests were also conducted where the bearings were subjected to overload and loss of lubrication. Only in a few cases was the Kurtosis technique successful in detecting damage [18]. Even in these successful instances, the amplitude of this parameter decreased significantly after an initial rise suggesting that the waveform of the time domain signal became increasingly more random as failure progressed. These results clearly showed that the Kurtosis parameter, although useful in some forms of failure, could not be relied on as a trending parameter for the purposes of prognosing bearing condition.

The trends recorded by the Crest factor were surprisingly similar to that recorded by the Kurtosis. Of the several tests conducted, the largest discrepancy occurred in the example shown in Figure 9. In some cases, the trends recorded by both parameters were almost identical. The implications are that simple Crest factor meters which cost significantly less than Kurtosis meters, can instead be used in place of the latter for monitoring rolling element bearing condition.

3. THE FREQUENCY DOMAIN

Digital fast Fourier analysis of the time waveform has become the most popular method of deriving the frequency domain signal. The signature spectrum so obtained [13] can provide valuable information with regard to machine condition. Enveloping or demodulating the time waveform prior to performing the fast Fourier transform is also gaining popularity and is included in the following discussion on frequency domain techniques. Finally, spectral information can also be derived using analogue filter sets tuned to passing the information only in bands of interest. Each of these techniques can be related as shown in Figure 10.

3.1 The Signature Spectrum

The vibrational characteristics of any machine are to some extent unique, due to the various transfer characteristics of the

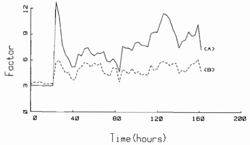

Figure 9: The Kurtosis ——— and Crest factor — — — trends for outer race damage at 21 hours of operation

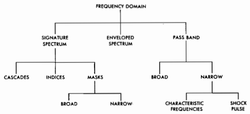

Figure 10: The frequency domain

machine. The method of assembly, mounting and installation of the machine, all play a part in its vibration response. Consequently, when a machine has been commissioned, a signature spectrum should be obtained under normal running conditions. This signature will provide a basis for later comparison in order to locate those frequencies in which significant increases in vibration level have occurred. Figure 11 is an example of how effective signature spectral comparisons can be in both detecting and diagnosing failure. Failure was induced on this occasion by removing lubrication on several occasions in a gearbox. The final spectra clearly recorded increases throughout the frequency range. The arrows indicate the positions of those frequency components related to the gear mesh component and two harmonics. Indeed this technique of spectral comparisons is widely used. Often an operator records on site data on a tape recorder and analyses them in the laboratory or office using a digital real time fast Fourier analyser. Manual comparisons are then made. More recently, the process has been automated somewhat by using portable microprocessor instrumentation with memory and some intelligence. These devices simplify the data acquisition process and the amount of housekeeping required as reliable interfaces with appropriate computers are available.

3.1.1 Cascades

Signature spectra can also be compared by plotting successive spectra with respect to time in the form of cascade plots. In this fashion, a developing fault can sometimes be easily recognised [18]. An example of spectral cascades is presented in Figure 12. An eddy current transducer was used to monitor the shaft relative displacement of the input shaft of a single stage gearbox. The gears were subjected to an overload condition and the signals of the shaft displacement transducer were monitored regularly. The spectral cascade obtained showed that significant amplitude increases occurred towards the end of the test, clearly indicating that a change in gearbox condition had occurred. This type of presentation can be used

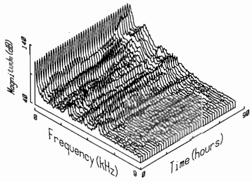

Figure 12: Spectral cascades

to present spectra derived from acceleration transducers too, provided the spectra do not contain too much information. In many cases, the harmonic content provided by acceleration transducers can be significant. This coupled with their large frequency response, normally produce cascade plots that are *cluttered* and therefore of limited use.

3.1.2 Indices

The amount of information present in a cascade plot can be reduced if each spectral change that occurred was expressed in a single number. Various indices have been proposed [19]. By and large, these spectral indices have been found to be more sensitive than time domain indices such as Peak and RMS levels in the monitoring of rolling element bearings [18], journal bearings [7] and, more recently, gears [20]. In some cases, the differences in trends recorded by the frequency domain parameters can be quite startling. Figure 13 depicts a comparison of trends of time and frequency domain parameters when applied to monitoring journal bearing condition. Lubrication was removed after approximately 0.5 hours after the start of the test. More damage was induced to the bearing by increases in the load to the bearing on two occasions as shown in the figure. The frequency parameter Matched Filter R.M.S. recorded increases in trends throughout the test duration. The instances when reductions were recorded occurred during applications of the load. Although amplitudes of the frequency domain parameter changed by as much as 15 dB, the performance recorded by the time domain parameters was disappointing. The reason for this difference in the trends of these parameters and the implications thereof particularly for monitoring journal bearing condition, had been discussed previously [7].

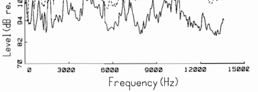

Figure 11: Gearbox casing acceleration signature spectra. ——— baseline spectrum, – – – spectrum of damaged gearbox; (a) gear mesh frequency, (b) second harmonic of gear mesh and (c) third harmonic of gear mesh

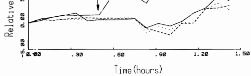

Figure 13: Trend Parameters; ——— Peak level (time), – – – RMS level (time), ... RMS × Kurtosis level (time), —·— Matched Filter RMS (frequency); (A) terminate lubricant supply, (B) impose light load and (C) increase load

3.1.3 Masks

An alternative method of trying to evaluate changes occurring in the signature spectrum is to form a spectral mask which is derived from the baseline signature plus an allowable tolerance limit [21]. Regular comparisons of new spectra with this mask will indicate if a problem is occurring. Sometimes, the narrow bandwidth spectrum is converted to a constant percentage bandwidth spectrum to compensate for speed variations. Broad masks are used if large speed variations are encountered. Similarly, narrow masks are used if only minor fluctuations in speed are anticipated. It is to be noted that a considerable amount of experience is required in the drawing-up of accurate maintenance limit masks, as vibration spectral amplitudes can also change under varying duty entries of the machine.

3.2 The Enveloped Spectrum

The enveloped spectrum has been shown to be particularly useful in monitoring machine elements that fail by producing relatively short duration impulses [22], a feature typical of incipient damage in rolling element bearings. Often incipient damage in rolling element bearings cannot be detected using signature spectral comparisons as the energy contributions by these impulses are usually swamped by the vibration components of more dominant elements or extraneous influences of nearby machinery. The technique involves firstly, a high pass filtering operation to remove dominating low frequency components in the spectrum. The resulting signal is then rectified partially or fully. A normal frequency spectrum is then derived using either a real time analyser or a computer. If the latter is used, then a low pass filter is also incorporated to prevent digital aliasing. The spectrum so obtained is sometimes also called the demodulated spectrum. Bearing damage in complex machinery has been detected with this technique [23]. Caution must be exercised when monitoring rolling element bearings with a more progressed failure mode, as these high frequency impulses are usually not present in data collected from such bearings. Hence, the technique may not be successful in detecting gross damage in bearings.

3.3 Pass Band Analysis

Yet another technique of reducing the quantity of data made available in a spectrum into manageable proportions is to only monitor a band of frequencies, either broad or narrow, in which defect frequencies of components are anticipated [24]. The monitoring of a narrow pass band is sometimes also known as characteristic frequency monitoring. Many of the existing vibration monitoring software packages that incorporate trending also allow characteristic frequency monitoring. Hence, for example, the trend of the gear mesh frequencies or bearing defect frequencies could be monitored. Again, this approach if used solely can present problems. For example, with reference to the gear mesh component and its harmonics shown in Figure 11, large amplitude increases were recorded by many other frequency components in the spectrum. Hence, trending a parameter that describes *all* components in some way, would provide a better measure of failure occurring.

The shock pulse method [25] may be considered to be a specialised application of characteristic frequency monitoring. Failure of high speed rolling element bearings results in energy being emitted at ultrasonic frequencies. This technique uses an accelerometer tuned mechanically and electrically to a frequency of 32 kHz to detect these distress signals. It is a relatively simple measurement and is widely used in industry to monitor high speed bearings.

4. THE QUEFRENCY DOMAIN

Quefrency is the absicca for the cepstrum which is defined as the spectrum of the logarithm of the power spectrum. It is used to highlight periodicities that occur in the spectrum in the same manner as the spectrum is used to highlight periodic components occurring in the time domain signal. The derivation of the cepstrum is not a trivial matter and care must be exercised when doing so [26]. Cepstrum analysis has predominantly been used in the analysis of gearbox vibrations [27]. Strong components can often be detected in the cepstrum due to the presence of modulation components or sidebands in the spectrum. An example is presented in Figure 14, which shows the cepstrum of a single stage 1:1 gearbox casing acceleration signal. The large component at 20.75 ms corresponds to the shaft fundamental modulation component and that at 41.5 ms is a rahmonic (equivalent to harmonic in spectral terms). The gamnitudes (similar to magnitude of spectral components) of these components usually increase with increasing wear in gears. There have been instances when cepstral quefrencies have recorded decreases in gamnitude. An example is presented in Figure 15. The "bandwidth" of the cepstral components were broadened so that gamnitude variations could be readily discerned. The diagram was obtained using casing acceleration signals from the single stage gearbox which was subjected to an overload condition. The initial increase in gamnitude of the fundamental component and its rahmonic was due to pitting in the pitch line of the spur gears. Continued operation caused further damage such as scoring of the addendum and deddendum of the teeth. The test was finally discontinued due to excessive vibration and

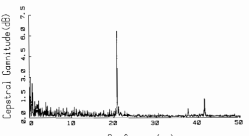

Figure 14: A gearbox casing acceleration cepstrum

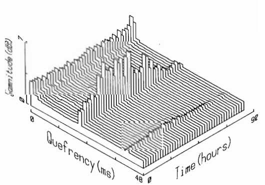

Figure 15: A cepstral cascade diagram

acoustic noise. Signature spectral comparisons showed that the base spectral noise level increased significantly with advanced damage and tended to overwhelm the shaft modulation components. Hence, the emphasis of the modulation components in the spectrum was reduced, resulting in the lowering of the gamnitudes of associated quefrency components.

Other forms of cepstral analysis include comparisons of signature cepstra and single number indices derived from successive cepstra in much the same way as signature spectral techniques and spectral indices are used. However, one must be prepared to accept reducing values which may be indicative of advanced failure modes.

5. CONCLUDING COMMENTS

It must now be evident to the reader that condition monitoring encompasses measurement and analysis techniques that belong to a wide variety of scientific disciplines. This article has been predominantly concerned with vibration analysis and has attempted to present an overview of the many techniques either being researched or used currently in industry. In the final analysis it must be emphasised that the majority of these techniques work best at detecting a single *symptom* of the machine malfunction. In the overall scheme where several different disciplines are employed, for example, spectrometric oil analysis can only provide information on the concentrations of wear metals in an oil sample. Particle counting on the other hand only provides information about the size and distribution of wear debris. Vibration monitoring is well suited towards the monitoring of rotating machinery and can present difficulties when monitoring reciprocating machinery.

Even within each discipline, subsets of techniques are available. For example, the major portion of this article was dedicated to various vibration analysis techniques suitable for monitoring machine condition. No one technique can provide *all* the answers. The Kurtosis technique may be suitable for monitoring rolling element bearings but is unsuitable for monitoring journal bearings. Similarly, cepstrum analysis is a useful tool in diagnosing gear failures but so far has not been employed in detecting rolling element bearing failures and with good reason. Consequently, it would appear that the detection, diagnosis and prognosis of wear or failure occurring in machinery can be greatly enhanced if a *syndrome* approach is adopted, in which a combination of symptoms identified by appropriate techniques are used to identify failure. This approach has not been widely adopted and has been partly due to the increased costs associated with utilising a wide array of techniques. Yet another reason for the low use of such an approach would be the strong preferences for individual techniques exercised by researchers and engineers currently involved in condition monitoring.

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An Anechoic Chamber at the Australian Defence Force Academy

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The Australian Defence Force Academy, incorporating a University College of the University of New South Wales, is located in Canberra adjacent to the Royal Military College, Duntroon. The first intake of students occurred at the beginning of 1986. Facilities have been built to cater for the needs of both teaching and research. In the field of acoustics, an anechoic chamber built within the Department of Mechanical Engineering Building has just been recently completed and is the only one of its kind in the Australian Capital Territory.

The anechoic chamber is a double-shelled construction. The outer shell consists of 190 mm thick reinforced concrete walls whereas the inner shell is a 106 mm thick Sonex-N reinforced enclosure (a lightweight metallic structure made by Grunzwig & Hartmann Montage GmbH), with a 50 mm thick fibreglass absorption lining being placed between the outer and inner shells. The inner shell is isolated from the outer shell by being supported on resilient steel springs which give a vertical resonant frequency of approximately 8 Hz. The surfaces of the inner shell are covered with 60 mm thick dented slabs made from fibreglass of density 50 kg/m^3. The dented slabs, being 540 mm deep with a taper angle of 14°, have been installed in staggered layers as shown in **Figure 1** and have been sprayed with a coating of Diofan (polyvinylidene chloride). The resulting free-field dimensions are 3.5 m x 3.5 m x 3.5 m between the tips of the dented slabs and the lower cut-off frequency is 150 Hz. The inner shell has a wire-mesh floor made of 3.2 m thick galvanized stainless steel cables, the mesh aperture being 60 mm. The load carrying capacity of the floor is 150 kgf/m^2. Five ceiling hooks have been provided for suspension of microphones and small items and two passage ducts of 80 mm diameter are available for passage of measuring cables.

The degree to which the anechoic chamber approaches an ideal free field has been tested by measuring the variation of sound pressure with distance along the radial direction from an omni-directional sound source according to ISO 3745 standard.

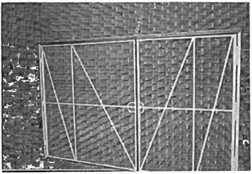

Figure 1. Interior view of the anechoic chamber showing dented slabs.

In a free field, the sound intensity varies according to the inverse square law, that is, inversely as distance squared from the source. **Figure 2** displays the average maximum deviations from the inverse square law of the traverses along two different microphone paths for the frequency range 100 Hz to 12.5 kHz. The length of traverse for each path is at least 2.6 m. The requirements of ISO 3745 have also been plotted in Figure 2 for comparison. Allowing 0.5 dB variation to account for the response of the measuring instruments and some irregularities of the movement of the microphone, the chamber adequately satisfies the ISO 3745 requirements for a lower cut-off frequency of 150 Hz.

A series of tests has been conducted to estimate the noise reduction through the chamber by operating a loudspeaker at various positions outside the chamber. The noise reduction through the chamber, evaluated as the difference in sound pressure level between the inner shell and the outside of the chamber, is shown in **Figure 3** and more than satisfies the minimum requirements. It must be noted that in all these tests only the inner door was closed and the outer door was completely opened. The noise reduction through the outer door is also included in Figure 3.

The anechoic chamber will be used for both research and industrial applications in the areas of loudspeaker response, directivity and sound power measurements of machines and rating of noise reduction devices.

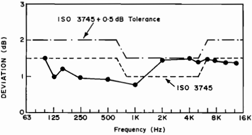

Figure 2. Deviations from inverse square law.

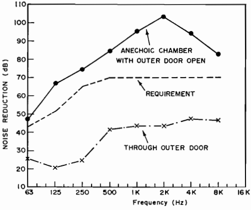

Figure 3. Noise reduction.

Applications of Underwater Acoustics to Australia's Maritime Defence

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ABSTRACT: Over the past three decades, Australian Defence Departments have sponsored significant research effort on aspects of underwater acoustics that have an effect on the performance of sonar systems. The reasons for this effort, and its achievements to date are discussed and related to changes in the requirements of the Maritime defence forces.

INTRODUCTION

There has been a great "technological change" in maritime warfare over the past few decades, stimulated of course by the Second World War and the subsequent "Cold War", and made possible by the advances in electronics that have been a feature of the 20th century.

Prior to this century, the navy's main form of remote sensing was the telescope, which assisted the human observer to detect, localise and classify significant objects within the field of vision. Advances in the science of electromagnetic propagation brought about radio and radar, while progress in acoustics enabled the introduction of underwater sonar (initially stimulated by the need to detect icebergs, decades before radar was developed). Sound is used for detecting underwater targets because, at useful wavelengths and frequencies, it is absorbed by sea-water far less than is any electromagnetic transmission. The average speed of sound in water is around 1500 m/s (compared with 2×10^8 m/s for light), so to generate a carrier sound signal with a wavelength of 10 cm, for example, a frequency of 15 kHz (toward the upper limit of average human audibility) would be required.

Radar and sonar have both played important parts during maritime warfare over the past few decades, and are expected to remain important for the foreseeable future. Their importance to Australia has recently been reported in the following terms: "Australia requires a manifest ability to detect, identify, and track potentially hostile forces within our area of direct military interest . . . modern technology in the form of over-the-horizon radar (OTHR) offers the prospect . . . broad-area real-time surveillance of our air and sea approaches out to 1500 nautical miles. Another promising new surveillance technology is the towed acoustic array, which is especially useful against submarines in favourable water conditions . . ." [Dibb, 1986, p. 6].

Over the past few decades there has been a steady emphasis on predicting the performance of a sensor within a given situation, and also on improving performance, by design changes, wherever possible. A conclusion drawn from these endeavours has been that the marine environment needs to be understood in considerable detail. In the Australian context, for example, this conclusion has been recently re-phrased as: "Australian hydrographic and oceanographic knowledge of our maritime environment is crucial to military operations in our own defence" [Dibb, 1986, p. 64]. Oceanographic parameters are complicated functions of space; many of them fluctuate significantly with time (particularly in the upper layers of the water column); and some of them can have critical effects on the performance of maritime defence equipment.

A feature of early sonars was that, in the absence of a perceived requirement to do otherwise, the dimensions of the transducers (projectors and receivers) were comparable with the wavelength of the carrier signal (which was generally some tens of centimetres). As a result, the width of the transmitted beam was large (say 30°). The phenomenon of background noise; either reverberation (the reception of large numbers of small random echoes from inhomogeneities in the medium), or ambient noise, was therefore significant but could be studied in terms of averages over comparatively large regions. Initial research into the properties of the ocean therefore emphasised a coarse-scale approach. To reduce the background noise, and hence improve the performance of these sensors, the beamwidth was decreased by increasing the transducer sizes. The effect of this has been that, in order to be able to predict the larger sensor's background noise level, the noise or reverberation producing properties of the ocean must be re-examined in finer detail. The noise problem was not "solved" by reducing the beamwidths, since with increasing capabilities by platforms and weapons to act at great distances, it has become necessary to detect targets at longer ranges (that is, still at low signal-to-noise ratios). Thus, although decades have elapsed, the need for environmental information has not (yet) diminished.

In addition to the design of better performing sensors, another important facet of naval operations is the routing of ships and submarines in order to (a) minimise time spent at sea; (b) minimise the time spent in enduring rough weather (for equipment performance); and (c) avoid regions where costly above-surface or undersea hostilities would be liable to occur. For the first two of these objectives, it is important to monitor large-scale features such as the ocean's "weather patterns" and their associated currents (as well as of the meteorological conditions). For the third objective, it is necessary to develop an atlas of the (slowly varying) ocean properties that affect sonar performance, as well as models of the rapidly varying properties in terms of observable parameters.

In this article then, we will first discuss sonar as an application of military oceanography, and describe the relevant environmental parameters. Secondly, we will summarise the progress that has been made by research into understanding these parameters, with emphasis on the ocean areas around Australia.

SONAR

The word "sonar" is applied to either a passive (listening) system or an active (echo-ranging) system; and both types have been in use since before World War II.

A. Active Sonar

Early active sonars operated at carrier frequencies of around 25 kHz, and the average detection range of submarines was only about 1 kilometre. The average detection range was subsequently increased in the post-war period, partly by reducing the carrier frequency (to improve the signal to noise ratio), and increasing the size (and hence mass and cost) of the systems commensurately. The Australian MULLOKA is an example of a modern active sonar, developed by DSTO over the past decade and currently fitted to several RAN vessels.

The signal-to-noise ratio at an active sonar is determined by:

(1) the loudness (source strength) of the pings emitted by a projector;

(2) the transmission loss that occurs from the projector to the target. Transmission loss is the ratio of the power output of the projector to the intensity at a given point and is a function of range from the transmitter;

(3) the target strength (scattering cross-section) of the target;

(4) the transmission loss from the target back to the projector (which is generally the same as item (2) unless the vessels are over a steeply sloping bottom);

(5) the self-noise of the sonar; and

(6) reverberation, a decaying noise-like signal heard by a receiver after every ping. Reverberation is caused by backscattering from inhomogeneities.

With the advent of long-range guided torpedoes and submarine-launched missiles, it has become desirable to detect submarines at long ranges. The limited detection ranges that are achieved by modern active sonars in some circumstances are due to a combination of the following factors:

(1) At typical sonar frequencies, beam-widths of realistically-sized transducers are such that significant reverberation is generated by biological scatterers such as deep-sea fishes with gas-filled swim-bladders (in deep-water), or by the roughness of the sea-floor and sea-surface (in shallow water). An important consequence of reverberation being the effective background noise is that there is nothing to be gained by increasing the output from the projector (the reverberation also increases and the signal-to-noise ratio remains unchanged).

(2) Since the transducer is affixed to the key of the ship (it is very expensive to deploy otherwise), the following problems occur:
   (a) the receiver's self-noise is increased by the proximity of the ship with its moving parts;
   (b) propagation in the horizontal direction is liable to degradation by (i) scattering and attenuation by gas bubbles generated by the moving ship and/or the wind; and (ii) downward refraction, when the water near the surface is heated and a negative sound-speed gradient is generated ("afternoon effect"). The effective horizon of the sonar can come in to a range of less than 1 km.
   (c) a submarine can often increase the transmission loss by remaining in the acoustic "shadow zone" in the thermocline beneath the surface mixed-layer.
   (d) the strength of the echo is decreased by twice the transmission loss that applies to the distance between the sonar and target.

B. Passive Sonar

With the realisation that the detection ranges of active sonars appeared to be limited, there has been an emphasis (especially since about 1970) on making the best possible use of passive sonar, which is basically an "array" of hydrophones (underwater microphones). A passive sonar simply listens for noises radiated by vessels (usually from their propulsion systems), and can be either mounted on the sea-floor, affixed to a submarine hull, towed by a vessel, or dropped into the sea by an aircraft (the "sonobuoy", of which BARRA is a modern Australian example).

The signal-to-noise ratio at a passive sonar is determined by parameters such as:

(1) The "loudness" of the target;

(2) The transmission loss that occurs from the target to the sonar; and

(3) The background-noise level at the sonar.

For stationary sonars, the noise is generally the ambient noise due to the effects of wind-driven surface-roughness, biological organisms or distant shipping. For moving sonars, flow noise is also a contributing factor, especially at the lower frequencies. Ambient noise can be reduced by designing a (large) directional system that responds only to sounds from a particular (but controllable) direction.

Frequencies low in the audio band are often used, for the following reasons:

(1) sound at these frequencies travels long distances in the ocean since the frequency is low enough that the effects of absorption, scattering, and bottom reflectivity on transmission loss are small;

(2) at these wavelengths, it is feasible to build an array of hydrophones that is sufficiently large to be highly directional; and

(3) ships and submarines radiate substantial amounts of noise at these frequencies.

ENVIRONMENTAL PARAMETERS RELEVANT TO SONAR PERFORMANCE

From the preceding chapter we can compile the following list of oceanographic parameters that can affect sonar performance:

Sea-surface roughness* and backscatter.
Sound-speed profiles in the ocean.
Acoustic properties of the sea-floor.
Acoustic propagation in deep water.
Acoustic propagation in shallow water.
Ambient sea noise.
Acoustic scattering.

We shall briefly review current progress in each of these fields, with emphasis on the Australian context. Several of these parameters (together with related oceanographic parameters) are being charted in Australia's maritime "area of direct military interest" (ADMI).

A. Sea-surface Roughness and Backscatter

Backscatter at short wavelengths (approximately 10 cm) is associated with the variation in the slope of the surface and is therefore dependent on the instantaneous wind-speed. Surface backscattering is anisotropic, in that the return from the downwind direction is less

***Footnote:**

This parameter is often referred to as a meteorological, rather than an oceanographic, parameter; but is included here for completeness.

than that from upwind. Damped capillary waves and short gravity waves tend to ride on the leeward, rather than the wind-ward, side of longer gravity waves. The result is that the leeward side of a long wave is steeper than its wind-ward side and therefore returns a stronger reflection.

Backscatter at long-wavelengths, to a first order aproximation, is associated with the larger-scale roughness that is at the "Bragg-resonance" wavelength. Since the surface waves are moving, the backscatter exhibits Doppler shifts. A sonar wavelength (λ_r) of 20 m for example is in resonance with surface waves that have a wavelength (λ_w) of 10 m. (The phase speed of these gravity waves is $V = \sqrt{(g\lambda/2\pi)} = 4$ m/s, and the frequencies of the Bragg peaks in the Doppler spectrum are $\Delta f = \pm 2V/\lambda_r = \pm 0.4$ Hz above and below the carrier frequency.)

B. Sound-Speed Profiles in the Ocean

A typical sound-speed profile in the ocean exhibits the following features:

(1) From the surface to a typical depth of several tens of metres (although occasionally zero), there is an isothermal layer in which the sound-speed slowly increases (or the refractive index slowly decreases) with depth. This surface mixed-layer refracts sound rays upwards (with a radius of curvature of around 90 km) to reflect off the surface, and therefore forms a surface-duct.

(2) Beneath the mixed-layer, there is a "thermocline" in which the temperature, and hence sound-speed, both have negative gradients. At medium and low latitudes, the thermocline extends to several hundred metres in depth.

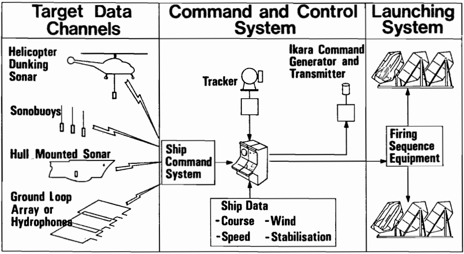
(3) At around 1 km depth, the temperature gradient becomes very small, and the sound-speed gradient increases to zero and continues to increase (to a value of 0.018 m/s per m at abyssal depths). At great depth (4-5 km) the sound-speed can increase to its value at the surface so that, regardless of the particular depth of the sea floor, the entire ocean layer is an acoustic duct.

C. Acoustic Properties of the Sea-Floor

Sea-floors are two-phase media in which the solid particles have variable properties such as chemical composition, grain-size distribution and degree of compaction (related to "porosity"). One approach to predicting their acoustic properties has been to treat them as a one-phase solid and to directly measure **in situ** the speeds and attenuation rates of the compressional and shear waves, and the density. With these quantities available, both the acoustic reflectivity (at any frequency and incident angle) and the behaviour of energy that penetrates the sea-floor, may be calculated. Measurements have been made of the acoustic interaction in the deep ocean using sources and receivers placed near the sea-floor, so as to provide a wide range of interaction angles, a stable predictable water environment above the sea-floor, and an absence of any effect due to the sea surface. These measurements have been modelled using computer programs, in order to determine the variation of sound speed with depth into the sea floor [Lawrence, 1985]. This type of experiment deals with the top few hundred metres of sediment, in contrast to the deeper depths that are examined by seismic profiling. Also, charts showing a variety of features including bathymetry, sediment type, and sediment thickness are being produced. Work has also been performed on surveying the geographical variation of bottom interaction properties, using the simpler procedure of near-surface explosive charges and hydrophones. These measurements determine the loss of acoustic energy on reflection as a function of angle and of frequency.

D. Deep-Water Acoustic Propagation

In general terms, deep water propagation is well understood, especially for cases where scattering near the sea-surface is unimportant, where variation in the horizontal plane is very gradual (so that mode-coupling is negligible), and where bottom roughness is not important. Under these conditions, well-established approximations to the acoustic wave equation (such as adiabatic mode theory or the parabolic equation theory)



Operational elements of the Ikara anti-submarine warfare system.

can be used to study the acoustic effects of oceanographic features such as mesoscale eddies. These studies have shown that such features have important effects on long-distance propagation, such as altering the range at which zones of high intensity occur [Lawrence, 1983] or refracting the sound horizontally to produce a "bearing error".

(1) Surface-duct propagation

The acoustic ocean surface-duct is analogous to the radar atmospheric humidity duct, although the **shape** of the refractive index profile in the duct differs (quasi-linear for the acoustic case, but quasi-exponential for radar).

The acoustic surface duct has a maximum, or cut-off, wavelength, which for the typical profile can be expressed as

$$\lambda_{max} = 8 \times 10^{-3} h^{3/2}$$

where λ_{max} is the maximum acoustic wavelength (metres), and h is the mixed-layer thickness (metres). For a typical layer thickness of 50 m, the maximum trapped wavelength is therefore 2.8 m which corresponds to a cut-off frequency of around 540 Hz.

For surface-duct propagation at high frequencies (above around 15 kHz), it is known that the transmission loss tends to increase with wind-speed even at short ranges where a direct ray can reach the receiver without reflecting off the sea surface. The reason for this effect is not well understood, but since it is mainly noticeable at high frequencies, it is believed to be due to scattering in the neighbourhood of the sea-surface [Hall, 1980].

The main environmental parameters that determine transmission loss in a surface-duct are surface-roughness (and wind-speed), the mixed-layer thickness and, when it occurs, near-surface solar heating.

Near-surface Solar Heating

Transient thermoclines, or small temperature rises, develop near the ocean surface when solar heating is high and the wind-speed is low. This "afternoon effect" (as the Navy terms it) causes rays from a shallow sonar to pass through the surface-duct rather than to be trapped by it. A one-dimensional thermal and mechanical diffusion model has recently been developed [Hill, 1983].

The one-dimensional model has been applied to regions in the deep ocean where horizontal variation is unlikely (in practical terms, this means far from boundary currents). The variable calculated was the probability that "afternoon effect" would occur for a period of some hours during an afternoon. It was found [Hill, 1983] that afternoon effect is unlikely to occur at latitudes higher than 40°S (due to the high average wind speed); whereas it is reasonably likely to occur in regions and seasons where the average wind-speed is low.

The assumption of one-dimensionality is not always justified, however, since it is liable to be inapplicable in frontal regions where there is a gradient in the sea-surface temperature. In the Tasman Sea, where large-scale eddies are continually formed, "steep" gradients of sea surface temperature are commonly found, and, on the cold side of a front, the vertical temperature profile can exhibit a near-surface temperature rise in addition to any solar heating effect.

Mixed-Layer Thickness (MLT)

Acoustic transmission improves as the MLT increases. High winds (storms) generate turbulence that increases MLT, whereas the cumulative effect of near-surface solar heating and mixing is to generate new (thin) mixed-layers. Work on modelling these processes is currently under way.

Surface-Roughness

Acoustic surface-duct transmission is degraded as the surface-roughness increases. Since MLT and roughness are both wind-generated (although MLT reflects the history of the wind over a period of several days) it is plausible that these two variables could be correlated. If the correlation were significant, there could be interesting effects on the probability distribution of transmission loss. For cases considered to date however [Hall and Sandy, 1985], the correlation between roughness and thickness is only about 10%, and the consequent effect on the probability distribution of transmission loss is insignificant.

(2) Convergence-Zone Propagation

At low frequencies (for which the surface-duct has no effect), long range propagation occurs via upward refraction at depths of 4 to 5 km. For a shallow sound-source, this phenomenon gives rise to "convergence-zone" propagation in which the sound rays (in the vertical plane) return to the surface, and partially re-focus there, at ranges of 60 km and multiples thereof. In the horizontal plane, convergence zones are annuli centred on the sound source. This phenomenon can also be compared with its skywave (Over the Horizon) radar analogue by calculating the ratios of horizontal skip distance to vertical "reflection" distance. The results, which are surprisingly close, are as follows:

(a) for convergence zone sonar, convergence range/refraction depth = 60/5 = 12; and

(b) for skywave radar, skip distance/reflection height = 1500/100 = 15.

This approximate agreement is only a coincidence, however, since the sonar ratio is determined by the variation in the acoustic refractive index of the ocean, whereas the radar ratio is determined by the angles at which radar beams are strongly reflected by the ionosphere.

E. Shallow-water Acoustic Propagation

The term "shallow-water" usually refers to regions over the continental shelf, where the depth of the sea floor increases to around 200 m. In general, shallow-water propagation is not as predictable as for the deep-water case, mainly for the reason that the sound-speed profile in the sea floor, which is now the dominant factor, is difficult to predict to the required precision.

Other factors that lead to a high variability in shallow-water propagation are:

(a) the importance of the shape of the sea-floor. Large scale roughness leads to horizontal refraction of the sound paths [Kamenyitsky, 1971], while small scale roughness yields bottom scattering and loss of coherence;

(b) the importance of the shape of the sound-speed profile in the water column. A negative-gradient (as occurs in summer) leads to short skip distances between successive bottom reflections; whereas a zero-gradient (typical of winter) leads to long skips between reflections. Thus the reflectivity of the sea-floor is a strong determinant under summer conditions, but is less of a limitation under winter conditions. The complement of this situation is that sea-surface roughness can be significant under winter conditions, but less important when the sound-speed gradient becomes negative.

In general, and for the reasons listed above, acoustic propagation losses in shallow water are higher (over the same horizontal range), and detection ranges of targets are correspondingly less, than occur in deep water.

F. Ambient Noise

Ambient noise levels in the ocean are consistently high because the low attenuation of sound allows sources at large distances to contribute. For example, ships distributed over an ocean basin produce a low frequency background noise referred to as traffic noise. Regions of high shipping such as the Tasman Sea show underwater sound pressure levels that are comparable to those of a busy city street. In regions of low shipping densities and poor propagation on the other hand, such as the Timor Sea, traffic noise levels are 20-30 dB lower [Cato, 1976].

The interaction of the wind and waves at the sea surface produces high noise levels which persist to the depths of the ocean, exceeding traffic noise levels in most areas once wind speeds rise above about 15 knots. Although this is the most important source of underwater noise, it is difficult to predict accurately, because a number of complex mechanisms of noise generation are involved and these are not yet well understood. Some of our recent theoretical work, however, has been successful in accurately predicting low frequency (less than 10 Hz) surface generated noise and is currently being applied to higher frequencies [Cato, 1983]. To test these theories and to improve our understanding of the noise generation mechanisms we are engaged in sophisticated experiments in laboratory tanks, reservoirs and at sea.

Marine animals produce a wide variety of sounds which although intermittent can at times dominate the background noise. In particular, there are regular choruses at sunset, and to a lesser extent sunrise, when the sounds of countless fish and invertebrates cause the ambient noise to rise by 20 to 30 dB [Cato, 1978b]. The occurrence of these choruses is sufficiently regular to be reliably predicted once the sources and their behaviour and distribution have been established. We are currently working with University biologists in this area.

The sounds of large whales are of sufficient intensity to affect sonar performance even though relatively small numbers of individuals are involved. The intense clicking sounds of sperm whales, which are plentiful in deep water, result in choruses of similar level to those of fish and invertebrates. However, they are far less predictable because of the nomadic behaviour of these whales. Herds of humpback whales produce a variety of intense sounds during their annual migrations along the Australian coastline [Cato, 1984]. Sonar operators need to be aware of the characteristics of these sounds so that when detected they can be recognised for what they are. One of the problems about quantifying these characteristics is that the sounds change from one year to the next.

G. Acoustic Scattering

In addition to propagation loss, the other environmental parameter that determines the performance of active sonars is acoustic backscattering.

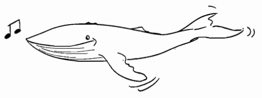
For shallow projectors in deep water, the reverberation that occurs is often due to inhomogeneities within the ocean medium ("volume backscattering"). Backscattering by the rough sea surface is usually unimportant because the grazing angle of the sound rays to the surface is very small (less than 2°), for both surface-duct and convergence-zone propagation (the vertical distance travelled by convergence-zone rays is due to refraction by the sound-speed profile rather than by the angle-of-launch that is important to OTHR). A further factor that contributes to sea-surface roughness being less important to sonar than to radar is that wave crests have higher slopes than do wave troughs.

Reverberation from a deep sea-floor is often negligible since, for a near-horizontal beam, it is due to backscattering at very long ranges (depending on the exact bottom-depth). Bottom reverberations received (from a very rough bottom) by sidelobes can be important, however, for some systems in certain range brackets.

The major scatterers in the ocean medium include bubbles, gas-filled swimbladders in fishes, and (for the higher frequencies) the various species of zooplankton. Bubbles and swimbladders have a resonance frequency that varies inversely with their average radius.

Swimbladders

For bladders, the resonance disappears at the small sizes due to friction within the bladder tissues [Hall, 1981]. Fish with swimbladders are distributed throughout the world oceans, although their population densities tend to depend on re-supply of nutrients. Most species form a "Deep Scattering Layer" (DSL) at depths of several hundred metres by day, and rise to the upper layers by night (to feed on the near-surface plankton). In the Australasian area the lowest levels of biological (volume) backscattering occur in the Coral Sea Basin [Hall, 1973a], while the highest values are found near the Chatham Rise south-east of New Zealand (an important commercial fishery area). An interesting DSL has been observed near the Equator, over the Ceylon Abyssal Plain south of the Bay of Bengal. This DSL was 1.7 km deep [Hall, 1971] and from its resonance frequency (of 3.5 kHz) the mass of the individual fish is estimated to be around 150 grams.



Bubbles

Bubbles scatter sound strongly, especially at their resonance frequency, and therefore scatter and attenuate sound significantly when prevalent. Scientists from Sydney University and RANRL have obtained photographically a reasonable number of measurements of wind-generated bubble size spectra under various wind conditions. The main results are [Walsh, 1986]: that very few bubbles are observed at wind speeds less than 6 ms^{-1}; that above that speed the number of bubbles increases as $W^{3.4}$ while the volume fraction of air to water increases as $W^{4.9}$ (W = wind-speed); and that the bubble-size spectrum has an r^{-4} slope (r = bubble radius). Walsh's work was for deep ocean conditions beyond the N.S.W. continental shelf. These results are in good agreement with analogous results already obtained overseas, which also showed that the bubble populations decrease quasi-exponentially with depth. Mulhearn [1981] developed mathematical models to explain the results of acoustic measurements of bubbles in coastal waters (off California) at low wind-speeds as being due to one population of bubbles attached to small particles in the water and stabilised by surfactant skins, and a second population arising from decaying matter on or in the sea-floor.

DISCUSSION

As can be seen from the previous chapters, there are many parameters that are relevant to the performance of the various types of sonar systems. For each of these parameters, it is desirable to know its spectrum (if applicable) and how it varies with position in space, and time (such as season, or time of day, depending on the parameter). Some parameters are determined by, or affected by, other environmental conditions that are easily monitored (such as surface roughness, or the sea-surface temperature). Many parameters are affected by conditions that are not easily monitored (such as size- and depth-distributions of deep-sea fishes, or the detailed structure of the deep-sea floor); and in these cases it is easier to measure the acoustic parameters directly (namely, volume backscattering strength and acoustic bottom reflectivity, for the above examples) than to measure the causative parameter and then deduce the acoustic effect. It is fortunate that the significant parameters that fluctuate in an apparently random manner (e.g., mixed-layer thickness) generally do so at depths that are not too great.

Like any branch of "mission-oriented" scientific research, the future paths that underwater acoustics will take are particularly difficult to foresee. As has happened in the past, advances in the science will stimulate technological innovations that will, in turn, generate new and unexpected questions about the marine environment.

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Predicting the Reactances of Irregularly Shaped Helmholtz Resonators by the Finite Element Method

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ABSTRACT: A procedure for using a standard structural finite element program, which can be run on microcomputers, for determining the reactive component of the specific acoustic impedance at the throat inlet of irregularly shaped Helmholtz resonators is described. The procedure is applied to three irregularly shaped Helmholtz resonators and the predicted results are compared with experimental measurements. It is found that there is good agreement. The significance of this work is that experimental measurements have been made to compare with the numerical solutions for a range of irregular cavities. The excellent agreement indicates that the numerical procedures can be used with confidence to predict important properties of Helmholtz resonators.

INTRODUCTION

Helmholtz resonators frequently occur in acoustic systems and they are often used in noise control equipment. A Helmholtz resonator essentially consists of a cavity and a throat as shown in Figure 1. The gas in the cavity is compliant and acts as a spring. The gas in and near the throat acts as a mass. At the natural frequency of the spring-mass system the "slug" of gas associated with the throat can be excited, by external acoustic pressure fluctuations of this frequency, into large amplitude oscillations. The frictional losses associated with these oscillations allow significant dissipation of acoustic energy at this frequency to occur.

Helmholtz resonators are sometimes incorporated into mufflers to enhance low frequency performance. Another common application is associated with perforated facings which are spaced from hard backing surfaces. Each hole of the facing can be considered to be the throat of a Helmholtz resonator.

Acousticians have been interested in Helmholtz resonators for many years and a substantial body of literature relating to these devices has been generated. A notable contribution to this literature was made by Ingard [1] who considered cavities of regular shape. However, Helmholtz resonators must often be of irregular shape so that they will fit into an available space. The performance of such irregularly shaped resonators cannot be reliably predicted by use of results such as those given by Ingard.

The purpose of this paper is to show that a standard structural finite element program, which can be run on a desktop computer, can be modified to determine, as a function of frequency, the reactive component of the acoustic impedance at the inlet to the throat of the resonator. Once the frequency dependent reactance is known, useful quantities such as the natural frequency and the bandwidth of the resonator when coupled to a specified system can be determined. An accurate knowledge of the natural frequency of a Helmholtz resonator is of importance as Helmholtz resonators are often used to control pure tone noise. It is noteworthy that accurate prediction of the natural frequency of a Helmholtz resonator is difficult when the throat length is small compared with the other throat dimensions because the effective throat length is dominated by end corrections associated with the "attached masses" at the ends of the throat.

The finite element technique described in this paper was used to predict the reactance at the inlets to the throats of three irregularly shaped Helmholtz resonators. The reactance of these resonators was measured by attaching them to the end of an impedance tube. The predicted and measured reactances are then compared.

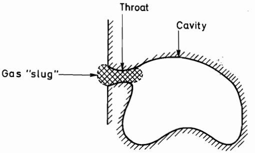

Figure 1: General Helmholtz Resonator

FORMULATION OF THE PROBLEM

Consider the arbitrary Helmholtz resonator shown in Figure 1. The required quantity, the specific acoustic reactance at the inlet to the throat of the resonator, is given by the ratio of the magnitude of the acoustic pressure at the inlet to the throat to the magnitude of the particle velocity at, and normal to, the throat inlet when the gas in the system is oscillating sinusoidally. The acoustic pressure, p, in the gas must satisfy the acoustic wave equation and the boundary conditions. The acoustic wave equation, in terms of the acoustic pressure, p, is given by Equation (1).

$$\nabla^2 p = (1/c^2)(\partial^2 p/\partial t^2) \qquad (1)$$

where c is the velocity of sound.

The linearised Euler equation, Equation (2), can be used to specify the effect of a rigid boundary. It is also useful in determining the particle velocity once the pressure field is known.

$$\nabla p = -\varrho(\partial \tilde{u}/\partial t) \qquad (2)$$

ϱ is the gas density and $\tilde{u}$ is the particle velocity, a vector quantity.

THE STRUCTURAL-ACOUSTICAL ANALOGY

Equation (1), subject to boundary conditions which can be defined by Equation (2), can be solved by a structural finite element program which incorporates regular linear elastic elements if the following structural-acoustical analogy is invoked.

Equation (1) can be written in cartesian coordinates as

$$(\partial/\partial x)(\partial p/\partial x) + (\partial/\partial y)(\partial p/\partial y) + (\partial/\partial z)(\partial p/\partial z) = (1/c^2)(\partial^2 p/\partial t^2) \qquad (3)$$

The x direction equation of motion in an elastic solid of density ϱ_s can be written as Equation (4):

$$(\partial\sigma_{xx}/\partial x) + (\partial\tau_{xy}/\partial y) + (\partial\tau_{xz}/\partial z) = \varrho_s(\partial^2 u_x/\partial t^2) \qquad (4)$$

σ_{xx}, τ_{xy} and τ_{xz} are the stress components and u_x is the displacement in the x direction. It is evident that Equations (3) and (4) are analogous if

$$\sigma_{xx} \equiv \partial p/\partial x,\ \tau_{xy} \equiv \partial p/\partial y,\ \tau_{xz} \equiv \partial p/\partial z,\ \varrho_s \equiv 1/c^2 \text{ and } u_x \equiv p. \qquad (5)$$

The structural-acoustical analogy can be completed by the following steps. If the structural displacement components in the y and z directions, u_y and u_z are made zero, the stress-strain relationships are given by Equation (6) and the strain-displacement relationships are given by Equation (7)

$$\begin{bmatrix} \sigma_{xx} \\ \tau_{xy} \\ \tau_{xz} \end{bmatrix} = \begin{bmatrix} C_{xx} & C_{xy} & C_{xz} \\ & C_{yy} & C_{yz} \\ \text{SYM} & & C_{zz} \end{bmatrix} \cdot \begin{bmatrix} \xi_{xx} \\ \gamma_{xy} \\ \gamma_{xz} \end{bmatrix} \qquad (6)$$

$$\xi_{xx} = \partial u_x/\partial x,\ \gamma_{xy} = \partial u_x/\partial y,\ \gamma_{xz} = \partial u_x/\partial z \qquad (7)$$

Thus if $C_{xx} = C_{yy} = C_{zz} = 1$ and $C_{xy} = C_{xz} = C_{yz} = 0$ and $u_x = p$ then the structural-acoustical analogy relationships of Equation (5) will be satisfied.

At rigid boundaries, the particle velocity normal to the boundary is zero and so by Equation (2)

$$n_x(\partial p/\partial x) + n_y(\partial p/\partial y) + n_z(\partial p/\partial z) = 0 \qquad (9)$$

n_x, n_y and n_z are the direction cosines of the local normal to the boundary. Thus by the structural-acoustical analogy Equation (9) becomes

$$n_x\sigma_{xx} + n_y\sigma_{yy} + n_z\sigma_{zz} = 0 \qquad (10)$$

This equation requires that the structural analogy of an acoustically rigid boundary is a traction free boundary.

Hence, in summary, a structural finite element program can be used for acoustical purposes by taking the following steps:

1. At all nodes all degrees of freedom except that associated with u_x ($\equiv$ p) are set to zero.
2. At nodes where the acoustic pressure is zero, u_x ($\equiv$ p) is set to zero.
3. The elastic element properties in Equation (6) are defined by $C_{xx} = C_{yy} = C_{zz} = 1$ and $C_{xy} = C_{xz} = C_{yz} = 0$.
4. The structural density ϱ_s is replaced by $1/c^2$.
5. At nodes on rigid boundaries no action is taken.

Once the proceeding steps have been taken the eigenvalues and eigenvectors of the acoustical system can be determined using standard algorithms in the finite element package. The acoustic pressures p, ($\equiv u_x$) can be found and these can be used to determine quantities such as the particle accelerations and velocities by use of the numerical approximation to Equation (2), the linearised Euler equation.

The analogy which has just been described is not new. It is, for example, given in [2] and [4]. The finite element method has, however, been developed predominantly for structural applications and while structural engineers are familiar with its use, the same appears not to be true for designers of acoustical systems.

We also note that the finite element method can be used to model the acoustic Equation (1) directly. This would lead to a specialised acoustic code which would avoid the need for implementing the analogy described in this section.

Using the Finite Element Method to Determine The Reactance of Helmholtz Resonators

The Helmholtz resonators considered had the shapes shown in Figure 2. The dimensions shown are internal dimensions. The throat width for all resonators was 20 mm and the internal divider was 3 mm thick. They are reasonably regular because they could be readily manufactured this way.

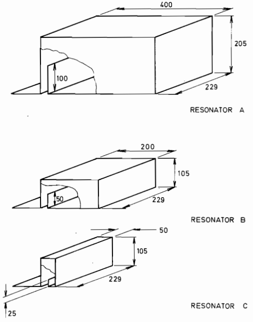

Figure 2: Resonator arrangements

It is possible, because of the prismatic shape of the resonators shown in Figure 2, to obtain the required results by analysis of a two dimensional finite element model such as that shown in Figure 3. However, there would be no problem in implementing a three dimensional finite element model if this was necessary. It can be seen with reference to Figure 3 that the cavity is divided into rectangular subregions ("finite elements") connecting "nodes" defined at the corners of each element. The acoustic pressure is assumed to vary linearly on each element between values at the nodes. The values of the acoustic presssure at each node then become the unknown parameters which must be determined. The elements can have an arbitrary quadrilateral shape but the use of standard mesh generators leads to the rectangular shape conforming to the geometry of the cavity shown in the figure. The long pipe attached to a resonator provides the driving acoustical system with a broad range of frequencies both above and below the natural resonance frequencies of the resonator when connected to an infinite half space.

The finite element mesh shown in Figure 3 was typical of that used to model the cavity and the throat. The mesh was refined near the entrances to the throat to give an accurate representation of the added mass which extends the "slug" of air shown in Figure 1 outside the throat. The mesh contained 522 nodes defining 455 elements.

The finite element program used was the STRAND finite element system [3] implemented on an NEC/APC III personal computer. This program is also available on equivalent IBM and SPERRY microcomputers. The subspace algorithm provided with the software was used to determine the lowest 15 resonant frequencies of the combined system. The lowest and highest of those frequencies for the resonator B, for example, were 40 and 950 Hertz compared to the lowest natural frequency of the resonator of about 200 Hertz.

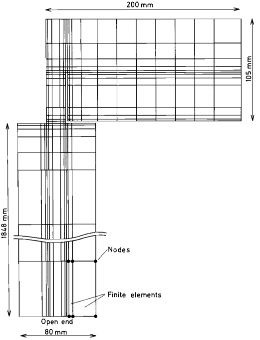

Figure 3: Typical finite element model

A modal analysis procedure [2] was then used to determine the response of the system to a driving sinusoidal acceleration at the open end of the long pipe. Light modal damping ensured that numerical instabilities did not occur at the natural frequencies of the system. At each frequency the amplitude of the pressure and velocity were determined as averages across the inlet to the throat and the ratio taken and plotted on Figures 4, 5 and 6.

The finite element approximation is known to converge with refinement of the model by reducing the size of the "elements" used. As a final check a refined model, in which each element shown in Figure 3 was divided uniformly into four elements to

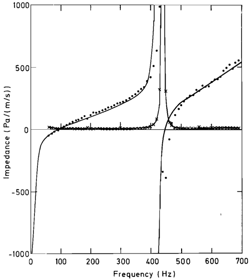

Figure 4: Predicted (—) and measured (•) throat reactances for resonator A. Measured resistance (X).

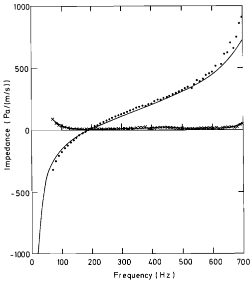

Figure 5: Predicted (—) and measured (•) throat reactances for resonator B. Measured resistance (X).

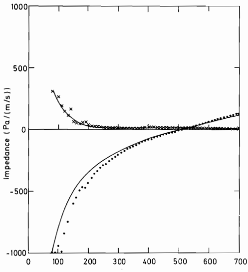

Figure 6: Predicted (—) and measured (•) throat reactances for resonator C. Measured resistance (✕).

give the model shown in Figure 7 (1967 nodes defining 1820 elements), was used to determine the 40 lowest natural resonant frequencies and vibration modes of the system. The plot of the results from the modal analysis for the original and the refined model gave a plot on Figure 5 indiscernable from the original curve, indicating that an accurate solution had been obtained on the coarse mesh and that, in fact, a simpler mesh could probably have been used.

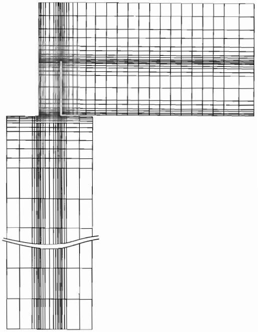

Figure 7. Refined mesh

MEASURED RESULTS

The specific acoustic impedance at the inlet to the throat of each of the three resonators shown in Figure 2 was measured so that the reactive component of the measured impedance could be compared with the predicted result. The measurements were made with a standing wave tube and details of the measurement procedures are given in Appendix A.

The measured specific acoustic reactances are superimposed on Figures 4, 5 and 6 to allow ready comparison with the predicted results. The measured resistive components are also shown as a matter of interest. The agreement between the calculated and measured reactances can be seen to be good. It can be seen from Figure 4 that there is a second resonance in the frequency range over which measurements could be made. The natural frequency of the resonators (where the reactance is zero and the reactance curves cross the horizontal axis) is predicted very accurately by the numerical method, together with the slope of the reactance line at this point. These two items are the critical data in the design of efficient resonators. The greatest difference between the calculated and measured reactance occurs at frequencies where the magnitude of the impedance becomes very large.

CONCLUDING REMARKS

In this paper we have described the application of a standard structural finite program, which has been implemented on microcomputers, to the problem of determining the reactive component of the acoustic impedance of irregularly shaped Helmholtz resonators. A procedure for the experimental determination of the same characteristics for resonators has also been described and applied to three specific designs with aspect ratio parallel to the throat varying from 0.5 and 2.0.

The agreement between the experimental and numerical results is excellent and indicates that the finite element procedures can provide data for the design of practical resonators. The significance of these results lies predominantly in the fact that they were obtained using standard finite element software on a personal computer and therefore provide a relatively inexpensive design tool compared to either full scale testing, such as the experimental work conducted as part of this project, or the use of larger finite element systems on mainframe computers.

The definition of the finite element model requires a compromise between the expected accuracy and the computational time required to determine the natural frequencies of the system. The original model of 455 elements required approximately 15 hours on the microcomputer to determine the lowest 15 natural frequencies and vibration modes. The calculation of each point plotted on Figures 4, 5 and 6 requires an inexpensive super-position and the time required is directly proportional to the numbers of points plotted. The extended time to solve for the eigenvalues and eigenvectors is of little consequence because none of the significant cost items for the analysis are directly related to the execution time and the modern personal computer is reliable enough for executions without continuous monitoring either overnight or while the designer gives attention to other tasks.

(Received 12 August 1986)

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4 MSC/NASTRAN Theoretical Manual, MacNeal Schwendler Corporation, Los Angeles.

APPENDIX A

EXPERIMENTAL DETERMINATION OF THE REACTANCE AT A RESONATOR THROAT INLET

The specific acoustic impedance at the inlet of a resonator throat was measured with a standing wave tube. The general arrangement of the system is shown in Figure A.1. A single resonator, 229 mm wide, was attached to one end of a plastic pipe with an internal diameter of 229 mm and a length of 6000 mm. The resonator throat was located so that it was symmetric with respect to the pipe cross section. A horn driver was located at the other end of the pipe. A probe microphone, whose position with respect to the face of the resonator could be measured, was used to measure the sound pressure in the tube.

At frequencies which are less than the first cut-off frequency for the pipe, which is about 750 Hz for the 229 mm inside diameter pipe used here, only plane waves will be present in the pipe. Interference between the plane wave incident on the resonator and the plane wave reflected from the resonator will produce a standing wave whose spatial variation can be explored by the probe microphone. The specific acoustic impedance at the interface between the tube end and the resonator can be deduced from the measurements made with the probe microphone and so the specific acoustic impedance at the inlet of the resonator throat can be deduced. The relevant theory is now developed.

The complex representations of the incident and reflected waves in the pipe are shown in Figure A.2. The terms $e^{-\alpha x}$ and $e^{\alpha x}$ associated with the incident and reflected waves account for the fact that the waves decay in the direction of propagation. Although, over distances of the order of the pipe length $\alpha x << 1$ so that $e^{\pm \alpha x} \approx 1$, it is still necessary to consider the effects due to the decay of the waves.

The specific acoustic impedance at the interface between the end of the pipe and the resonator face, $\tilde{z}_s$, can be written as the ratio of the complex representation of the pressure at this point $\tilde{P}_i + \tilde{P}_r$ to the complex representation of the velocity at this point $(\tilde{P}_i - \tilde{P}_r)/\varrho c$. Thus Equation (A.1) can be written

$$\tilde{z}_s = \varrho c[(\tilde{P}_i + \tilde{P}_r)/(\tilde{P}_i - \tilde{P}_r)] \quad \text{(A.1)}$$

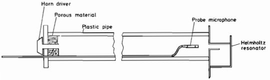


Figure A.1: Standing wave tube

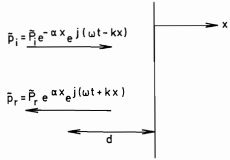


Figure A.2: Wave representation

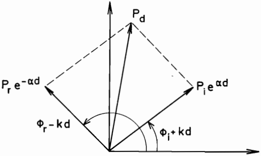


Figure A.3: Representation of P_d on the complex plane

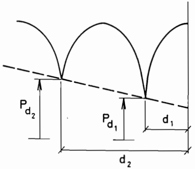


Figure A.4: Variation of P_d with d

Since $\tilde{P}_i$ and $P_i e^{j\phi_i}$ and $\tilde{P}_r = P_r e^{j\phi_r}$, the following can be written

$$\tilde{P}_r/\tilde{P}_i = Re^{j\Delta} \quad \text{(A.2)}$$

$$R = P_r/P_i \text{ and } \Delta = \phi_r - \phi_i \quad \text{(A.3)}$$

Thus the normalised specific acoustic impedance, $\tilde{z}_s/\varrho c$, can be written as

$$\tilde{z}_s/\varrho c = (1 + Re^{j\Delta})(1 - Re^{j\Delta}) \quad \text{(A.4)}$$

The normalised resistive and reactive components of the specific acoustic impedance $r_s/\varrho c$ and $x_s/\varrho c$ can then be written as

$$r_s/\varrho c = (1 - R^2)/(1 + R^2 - 2R\cos\Delta) \quad \text{(A.5)}$$

$$x_s/\varrho c = 2R\sin\Delta / (1 + R^2 - 2R\cos\Delta) \quad \text{(A.6)}$$

The preceding quantities relate to the face of the resonator. They can be readily related to the inlet of the resonator throat by multiplying them by the ratio of the area of the pipe cross-section to the area of the resonator throat. It is evident that R and Δ must be found. These quantities can be found from the measurements made with the probe microphone as shown in the following.

The complex representation of the acoustic pressure at a point at a distance d from the interface between the end of the tube and the resonator is

$$\tilde{P}_d e^{j\omega t} = (P_i e^{j\phi_i} e^{\alpha d} e^{jkd} + P_r e^{j\phi_r} e^{-\alpha d} e^{-jkd}) e^{j\omega t} \quad \text{(A.7)}$$

$\tilde{P}_d$ can be represented on the complex plane as shown in Figure A.3. It can be seen that as d varies P_d will vary. A representative plot of P_d against d is shown in Figure A.4.

It can be seen from Figure A.3 that the minimum value of P_d which is closest to the face of the resonator occurs when there is a difference of π between the arguments of the complex representation of the incident and reflected waves. Suppose that this value of d is denoted d_1. Thus

$$(\phi_r - kd_1) - (\phi_i + kd_1) = \pi \quad (A.8)$$

This equation can be written as

$$\triangle = \phi_r - \phi_i = 2kd_1 + \pi \quad (A.9)$$

Since $k = 2\pi/\lambda$, this equation can be written as

$$\triangle = \pi[(4d_1/\lambda) + 1] \quad (A.10)$$

Thus by measuring d_1, the distance of the first minimum from the face of the resonator it is possible to determine $\triangle$ which is needed in Equations (A.5) and (A.6). It now remains to find R.

Suppose that the ratios of the maximum pressure to the pressures at the first and second minima are measured. It can be seen from Figure A.3 that the maximum pressure will be approximately $P_i + P_r$. The first minimum, which occurs at d_1, will be $P_i e^{\alpha d_1} - P_r e^{-\alpha d_1}$ while the second minimum, which occurs at d_2, will be $P_i e^{\alpha d_2} - P_r e^{-\alpha d_2}$. Suppose that the ratios of the maximum to these minima are written as

$$1/\psi_1 = (P_i + P_r)/(P_i e^{\alpha d_1} - P_r e^{-\alpha d_1}) \quad (A.11)$$

$$1/\psi_2 = (P_i + P_r)/(P_i e^{\alpha d_2} - P_r e^{-\alpha d_2}) \quad (A.12)$$

Since $R = P_r/P_i$, $d_2 = d_1 + \lambda/2$ and $\alpha d << 1$, the preceding equations can be written in the following form by use of the result $e^\theta = 1 + \theta + \theta^2/2 + \ldots$, which for $\theta << 1$, can be approximated as $1 + \theta$.

$$1 + \alpha d_1 - R(1 - \alpha d_1) = \psi_1(1 + R) \quad (A.13)$$

$$1 + \alpha d_1 + (\alpha\lambda/2) - R[1 - \alpha d_1 - (\alpha\lambda/2)] = \psi_2(1 + R) \quad (A.14)$$

Subtracting Equation (A.13) from Equation (A.14) gives

$$\alpha = 2(\psi_2 - \psi_1)/\lambda \quad (A.15)$$

Substitution of this result in Equation (A.13) yields the following equation for R.

$$R = [1 - \{\psi_1 + 2d_1(\psi_1 - \psi_2)/\lambda\}] / [1 + \{\psi_1 + 2d_1(\psi_1 - \psi_2)/\lambda\}] \quad (A.16)$$

ψ_1 and ψ_2 can be conveniently found by measuring the decibel difference between the maximum and the minima. This value of R, along with the value of $\triangle$ found from Equation (A.10) can be used in Equations (A.5) and (A.6) to find the required results. □

A doctor's sound dictionary

Ever wondered what your doctor's listening to when he places that cold, shiny stethoscope on your chest? A University of Queensland researcher has the answers. He has just developed the world's first dictionary of the different chest sounds a doctor hears.

Professor Charles Mitchell compiled the audio-visual tape after he found difficulty teaching his students the multitude of sounds in patients' chests.

"It's extremely hard to teach students and even doctors the different sounds. You obviously can't listen in at the same time," said Professor Mitchell, from the university's department of medicine.

But now Professor Mitchell, with the aid of computer graphics, film footage and real-life sounds, can explain what it's like listening to a patient with asthma, bronchitis, pneumonia, fluid accumulation and even lung cancer.

The more basic sounds, from a normal pair of lungs to crackles, wheezes and gurglings, have also been immortalised on tape.

"It has always been easier in training to see what something looks like, to show them a picture or let them feel a lump in breast cancer or whatever," Professor Mitchell said. "Now they will not only know what particular diseases and conditions sound like but what they look like, for example when the bronchial tubes vibrate together to produce wheezing."

The video tape, which will assist medical students and form part of the in-service training for general practitioners and thoracic specialists, is an extension of Professor Mitchell's work in developing a system of classifying lung sounds to assist doctors in diagnosing medical conditions and establishing their severity.

(Chris Thomas in the Sydney Morning Herald, 14 Feb. 1987)

Current research in ultrasonics and physical acoustics

This now traditional annual meeting of the Physical Acoustics Group of the Institute of Physics was held at University College, London. It has been the custom for one of the centres active in various areas of physical acoustics to host the meeting and to provide a major part of the programme; hence half of the contributions were from workers at University College.

Several papers were on various aspects of ultrasonic wave scattering which are of importance in the development of nondestructive evaluation techniques. P. Smith (U.C.L.) discussed the problem of using ultrasonic scattering data to deduce the nature of the scattering object in a medium which is viscoelastic. L. J. Bond (U.C.L.) reported a recent advance in overcoming the zero-of-time problem which has led to some controversy over the application of 1-D Born inversion techniques for sizing defects. M. Punjani and L. J. Bond (U.C.L.) discussed the phenomena which occur when an ultrasonic wave is scattered by a partially closed crack. The natural occurrence of these cracks in solids poses a major obstacle to reliance on ultrasonic techniques for crack sizing and detection. M. Plant (U.C.L.) represented the college's close involvement in the development of the acoustic microscope, with a new analysis of the propagation of surface waves at the interface between the coupling fluid and the sample being investigated.

E. Aristodemou (British Geological Survey, Edinburgh) demonstrated that seismologists and those engaged in ultrasonic testing have much in common by relating to seismic data results obtained for wave propagation and scattering at a welded quarter space. All users of ultrasonics have an interest in transducers, which made an analysis by J. Engelbrecht (visiting the University of Surrey) of linear and nonlinear fields in the near field of an ultrasonic transducer particularly appropriate to a meeting of this kind. P. J. King (University of Nottingham) reported low temperature ultrasonic attenuation evidence of three distinct loss phenomena associated with vanadium centres in doped GaAs. A. McKie (University of Hull) described laser generation and detection of ultrasound and a system which is now being used for making ultrasonic measurements of solids at high temperatures. The potential of this system was demonstrated by detailed measurements of the temperature dependence of the velocity of sound in mild steel at temperatures in excess of 800°C.

The meeting was attended by about 30 people and will be remembered for both the high quality of the contributions and the lively constructive discussions that followed. The Group A.G.M. was also held during the day.

(D. P. Almond in Physics Bulletin, Feb. 1987)

Sounding out fractures

A fractured bone has a lower resonant frequency than an unfractured bone, because the area around the fracture is less rigid. This principle has been used by a team in the Medical Electronics Laboratory at the University of Kent to develop a technique for bone fracture assessment.

The method introduces into the bone a random noise at a very low level and the resulting movement is detected with an accelerometer. The output from the accelerometer is then analysed to give the frequency response of the bone, in both amplitude and phase. Breaks in the amplitude response occur at the resonant frequencies.

As well as detecting fractures, the method gives an electronic measurement of bone healing — something that conventional fracture detection methods cannot do. This is because the low resonant frequency of the broken bone slowly rises as the fracture heals, until it gives a frequency recording similar to that of an unfractured bone. For instance, an unbroken shin bone has a resonant frequency of about 730 Hz.

The technique, which has been tested on patients from the Kent and Canterbury Hospital and the London Hospital, has been patented by the university's industrial liaison company.

A simpler version of the technique has also been developed to measure the rigidity of the fracture. This is similar to the manual sensing method currently used, in which the limb is considered un-united if the consultant can flex the fractured bone. However this relies on the consultant's sensitivity to bone movement inside both skin and muscle; the new technique gives electronic objectivity.

A small vibration is introduced to the bone, then detected by an accelerometer, amplified and again introduced to the bone. Such a system oscillates at a frequency determined by the phase shift round the system and, in particular, by the phase shift through the fracture. A non-rigid fracture has a large phase shift and as a result the oscillation frequency drops. Again, this measurement can be used to monitor bone healing, as the oscillation frequency should return to that of the surrounding unfractured bone.

(Physics Bulletin, Feb. 1987)

Time-warped speech

In the 1960s most researchers assumed that speech recognition was simply a matter of distinguishing the "shape" of each "phoneme" (syllable or consonant group) and translating that into words. But that aproach has proved unrewarding because it underestimates the variability and ambiguity of speech. Compare "This new display can recognise speech" with "The nudist play can wreck a nice beach".

Today a different mood prevails. I.B.M.'s Dr. Fred Jelinek jokes that his system improves every time he gets rid of an "expert". What he means is that given lots of data, computers are better at deducing what to measure so as to distinguish words than humans are. At its simplest this means measuring the statistical similarity between a stored template (of a word usually) and the sound that has been heard.

But it is never as easy as that. For a start, words vary in length according to the speed at which they are spoken and according to their context. They have to be "time-warped" to a standard length. But it does not help to time-warp them by a set amount. Say the word "three" slowly and it is the "ee" that gets lengthened, not the "thr". The answer is dynamic time-warping, a mathematical trick that matches two spectrograms of uneven length.

But if you try hard enough you can dynamically time-warp one word into almost any other. The time-warping has to be constrained. The cleverest way of doing this leads to a whole new approach to speech recognition called "hidden Markov modelling", after a Russian mathematician who analysed the opera, Eugene Onegin. It was first applied to speech recognition by Mr. Jim Baker, now the chief executive officer of Dragon Systems.

It gets away from the idea of comparing word templates, comparing instead tiny fragments of speech with stored patterns and, in particular, the probability that one fragment will be preceded and followed by another. It is "hidden" because the answer it gives for each sound is itself statistical and based on the computer's own ability to learn from examples.

The statistical approach stumbles over short words, not long ones, which include more distinctive features. "Disestablishmentarianism" is easier than "it", "if", "is" and "in". This is where the linguistic rules come in. "In America" is a more likely phrase than "it America", but "if America" and "is America" are both plausible. No single approach, acoustic or linguistic, is as good as their combined efforts.

(The Australian, 18 Nov. 1986)

Bangkok also has problems

Discotheques violating city noise and light levels face closure from next month, Environmental Health Division Director Voravit Lebnak said yesterday. A Bangkok Metropolitan Administration ordinance issued in 1986 set the maximum noise level at 90 decibels and banned laser beams.

The ordinance was issued after the B.M.A. organised a meeting between 50 discotheque operators and officials from the division and Public Health Ministry. So far, 39 discotheques have been allowed to operate because they comply with the regulations.

From next month, said Dr. Voravit, B.M.A. officials will inspect the discotheques. Violators will get a warning for a first offence and subsequently face 15-day or indefinite closure. Dr. Voravit said people who are subject to excessive noise once or twice a week are prone to hard hearing. He said laser beams for illumination can cause cell coagulation or inflammation, which may lead to blindness.

(Bangkok Post, 17 Oct. 1986)

A computerised Bosendorfer?

The famous Viennese piano manufacturers Bosendorfer have come up with the ultimate way in which you can have, say, Vladimir Ashkenazy or Andre Previn playing in your own living room. Like recordings, they would not actually be there. But the sound you would hear would be every bit as "live" as the moment the performers originally played the notes. Or any pianist could be heard "playing" at a concert when they were on the other side of the world.

The piano company is trumpeting the arrival of its new computer piano system — the Bosendorfer 290SE — as a breakthrough in piano reproduction that will revolutionise the business. The basis of the system is an optical device that scans the keyboard action 800 times a second as the piano is being played and stores the information digitally on an audio cassette. By playing back the cassette, the keys are activated in exactly the manner of the pianist with all the weight, speed and style used in the original performance.

A pianist playing in one concert hall could be heard simultaneously elsewhere as the signals could be passed from one Bosendorfer 290SE to another. "This is vastly in advance of the old piano-roll system which reached a peak of popularity in the 1920s before the advent of records," saids one of the Bosendorfer experts who has been engaged on the project for the past 14 years. "But this piano is unlikely to be bought by many people for enjoyment in their front rooms. It costs about $140,000 and is a serious tool likely to be of most use to music colleges and recording studios."

Students could use it to compare one performance with another and it would be possible to listen to performances of the great maestros of the day if they could be persuaded to play programs for the tape system. "Tapes could be reproduced and distributed to all purchasers of the computer piano system," the spokesman said.

The equipment can easily be used to make corrections to imperfections that always crop up in performance, so Bosendorfer expect to sell 290SEs to top-line record companies. "All it takes it a computer terminal and it would be an enormous saving in time and labour to make corrections and alterations before the recording engineers start work on a tape," the piano-man said. Eventually, Bosendorfer hope to bring the equipment to Australia.

(The Australian, 11 Nov. 1986)

Information for Contributors

Articles for publication normally occupy 4-5 printed pages (approximately 4 pp. double-spaced typing per page). Authors may be asked to pay additional typesetting charges for pages in excess of 5. Frequent headings and sub-headings are desirable and an abstract of approximately 200 words should be included. Reprints may be ordered, preferably prior to printing (they are then cheaper).

Diagrams will normally be reduced to single column width: authors are requested to plan diagram proportions and letter size accordingly. Full stand-alone captions should be provided for each diagram (these will be typeset).

Types of articles accepted include technical, tutorial and review. Short reports (1 page printed) on current research or a group's activities are welcome, as are shorter notes for inclusion under Technical Notes.

NEW PRODUCTS

CIRRUS

SELF CALIBRATING SLM

Cirrus Research have updated and improved the concept of a self calibrating SLM, first introduced by the CRL 2.21B, with the new CRL 2.21C. The new unit retains all the features of the original, including accuracy to BS 5969 Type 2 with true acoustic calibration and adds several new features to enhance the measurement performance.

The CRL 2.21C now measures down to 35dBA and up to 130dBA. This allows the same unit to be used for neighbourhood noise as well as general industrial noise in a factory environment. Additionally, an optional computer interface can be specified to replace the standard ac output. This allows the CRL 2.21C to be used with data acquisition software from one of the many programmes available from Cirrus Research or several other companies round the world who have written such software.

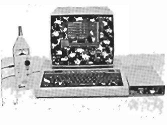
Finally, the CRL 2.21C is delivered complete with a rugged carrying case which uniquely allows the CRL 2.21C to be used to full acoustic performance without removing it from the case. The case contains a compartment for the gooseneck microphone, the windshield and calibration screwdriver.

SHORT Leq SOFTWARE

The design and protocol for the DP37 interface is jointly agreed between Cirrus Research, the originator, Soeur-Anne SA (France) and Quest Electronics (USA). The protocol, together with the L3M microphone interface and DP15 analogue bus permit direct connection between units of different manufacture, while allowing each individual unit to operate to full performance. Thus a computer from one source will operate with software from a second or indeed with hardware from a third. The DP37 copyright is jointly held by the three companies.

Using the technique of 'Short Leq' any index such as L10, L90 or overall Leq can be built up by the computer from the basic samples. Each 'Short Leq' is a separate and distinct energy related measurement — a true Leq — carefully timed by the computer. Thus, by software, any period Leq longer than the basic element can be calculated AFTER the event. All the user has to do is acquire data blindly into memory. The Cirrus programmes can acquire data either from a computer Sound Level Meter, for example the CRL 2.36, CRL 2.39A, SA 10-11 or Micro 15 or from an analogue output meter such as the CRL 2.22, CRL 2.37A/3 or any DP15 equipped unit. Not all programmes are identical on different computers and different instruments but the programme 'cores' are the same.

The CRL 2.39A Real Time Analyser and the CRL 2.37A/3 and CRF 1.22 Octave Analyser have software to plot and display the octave bands. With the CRL 2.39A, the sixteen internal memories can be downloaded into the computer and plotted, or the unit can be used on line to display and store continuous real time octave spectra. Printer routines are included in the programmes to produce hard copy records. The real time programmes can also acquire dBA data samples in the same format as 'Short Leq' and thus the retrieval programmes will work together. Real time analysers from Audioanalyse types ATR11 and ATR22 will also function with the Cirrus software.



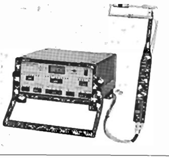
Programme suites for a particular instrument typically contain at least one acquisition programme, a disc initialisation routine, instrument control instructions and data retrieval routines, plus, in the case of frequency analysis, an octave acquisition programme. With the Acorn BBC computers no interface unit is usually needed for a single unit. However, as the IBM and Apple units, in standard form, do not have the same sophisticated interfaces as the ACORN; Cirrus interfaces are required to interconnect either the analogue signal or the DP37 interface.

Further information: M. B. & K. J. Davidson Pty. Ltd., 17 Roberna Street, Moorabbin, Vic. 3189. (03) 555 7277.

BRUEL & KJAER

PORTABLE SOUND INTENSITY ANALYSER

All those interested in reliable field measurements of sound intensity will welcome Bruel & Kjaer's new portable sound intensity analyser. It weighs 5.5 kg (12 pounds), is battery powered, and has an IEEE 488 parallel interface and a B & K serial interface. The Type 4433 is particularly easy to operate



with an automatic scan for sequential octave analysis and automatic ranging. It is easily calibrated, and there is a choice of three microphone sensitivities and 200 V, 28 V and 0 V microphone polarisation voltage.

A sound power determination can be done literally in minutes — in the field and to a high degree of accuracy. Other applications include sound intensity mapping to locate noisy components, and measurement of sound transmission in building acoustics.

The 4433 operates with either Sound Intensity Probe Type 3519 or Type 3520. These are two-microphone probes which use the pressure gradient technique. The Type 3520 was specially developed for use with the 4433 and includes a remote control handle so that measurements can be made without having to touch the instrument front panel. Type 3520 contains the phase- and amplitude-matched microphone pair Type 4813 which features the recently developed phase corrector units. Very close and stable phase matching is maintained between the measurement channels so that accurate measurements can be made in the difficult acoustical environments likely to be encountered in the field.

SPHERICAL HYDROPHONE AND UNDERWATER COONECTORS

The Spherical Hydrophone Type 8105 is the newest of B & K's range of underwater transducers. This robust spherical hydrophone can be used at ocean depths of up to 1000 m. It has excellent omnidirectional characteristics over the full frequency range of 0.1 Hz to 160 kHz. In particular, the 8105 is omnidirectional over 270 degrees in the vertical plane.

As with other B & K Hydrophones, the Type 8105 can be calibrated in the field with Hydrophone Calibrator Type 4223. A special adaptor has been developed for this purpose to fit the coupler otherwise used for the Type 8101.

Underwater Connectors JP/JJO415 are suitable for use with B & K Hydrophones Types 8101/4/5. The connectors are compatible with the older type, but are more robust and can be mounted in the field. This makes cable and connector repairs much easier as they no longer have to be made at the factory.

MATCHED MICROPHONE PAIR

Bruel & Kjaer's new Stereo Microphone Sets 3529 and 3530 consist of two carefully matched pairs of omni microphones for "spaced apart" (A-B) stereo recording. The sharp, clear stereo image which is gained by this recording method depends on close matching of the individual microphones for sensitivity, time and frequency response. Bruel & Kjaer's matched pairs have been hand-picked from microphones which have already undergone numerous stringent quality control procedures, final testing and individual calibration.

The best possible stereo image has been ensured by matching the microphones in the 3529 and 3530 kits to within 1dB in amplitude response over the entire frequency range 20 Hz to 20 kHz and within 10 degrees in phase over the range 50 Hz to 20 kHz.

In addition to standard accessories such as cable clips, windscreens, and a sonically designed mounting boom, the 3529/30 sets include two additional types of protection grid which allow the frequency response of the microphone to be tailored to individual recording needs.

Further information: Bruel & Kjaer Australia Pty. Ltd., 24 Tepko Road, Terrey Hills, N.S.W. 2084. (02) 450 2066.

ANITECH

RION SLM NA-24

The NA-24 Sound Level Meter is especially designed to be economical and suitable for field-use. It can be easily handled by people without any special skills in measuring sound level. Model NA-24 conforms to IEC 651 Type 2.

The features and functions of this instrument include:

- Maximum level hold
- Over and Under range indicator
- Pocket size and light weight
- Large and easy to read LCD
- Fast and slow dynamic characteristics
- AC and DC signal output for data analysis and recording.

Further information: ANITECH, 1-5 Carter Street, Lidcombe, N.S.W. 2141. (02) 648 1711.

VIPAC

NOISE DOSIMETER / SOUND LEVER METER

The LD700 with easy to read L.C.D. is a self-contained, user programmable instrument. Designed for occupational health and environmental noise measurement/monitoring applications. Features include an electronically locked keyboard for security; multifunction-simultaneous measurements; internal memory storage of information with time and day ident of noise events.

Stored information can be outputed via the units standard RS232 interface port — to thermal printers, cassette memory units, computer systems etc. for generation of hard copy reports in a wide variety of formats (e.g. time histories; exceedence levels listings, etc). Options include inexpensive application software packages, if required manufactured by Larson Davis Laboratories U.S.A. and exclusively represented by Vipac Pty. Ltd. — Instrument Division.

FIELD FFT ANALYSER

This unit is an exciting development in portable Acoustics and Vibration measurements — analysis instrumentation developed by Ono Sokki Co. Ltd. It weighs only 8 kg, incorporates a large LCD display, has inbuilt thermal printer and is a powerful stand alone analyser for dc to 20 kHz frequency applications. Separate direct inputs are provided for microphones and accelerometers in addition to the BNC and trigger inputs. Three way power supply (int. R/C Batt; Ext. dc; Mains) allows flexible usage. G.P.I.B. is standard and RS232 optional.

The CF210 provides full compliment of processing functions via menu selection, these include 1/3 octave band spectrum analysis, phase etc. A 3-dimensional (waterfall) display is standard as are numerically displayed lists of measured data. Cursors include to 20th Harmonic components search functions.

Internal memory (unaffected by power interruption) allows storage of 64 frames of displayed data thus eliminating the need for tape recorders in many applications.

Further information: Vipac Instruments Pty. Ltd., Mr. David Pentecost, 275-283 Normanby Road, Port Melbourne, Vic. 3207. (03) 647 9700.

EAR MUFFS

A Sydney rifleman who got tired of the sound of guns has developed an electronic device that may be fitted to earmuffs to allow the wearer to hear conversation while blocking out loud noises. **Mr. Hans Heim,** who supplies cleaning equipment to gunshops, fitted a microphone, loudspeaker and associated electronic circuit into standard earmuffs. Included in the circuit is a device to detect loud sounds and shut off the amplifier. At such times the 'hear muffs' simply operate as normal ear muffs. Similar muffs are available from overseas but cost much more. The muffs will be especially useful for shooters at firing ranges where they need the protection of ear muffs but also need to listen to instructions. The muffs would also be useful in industry.

A grant of $5000 has been made from the Advanced Technology Development Assistance Fund of the N.S.W. Department of Industrial Development and Decentralisation to help Mr Heim with production and marketing of his ear muffs.

Further information: Hans Heim, P.O. Box 560, Wahroonga, N.S.W. 2076. (02) 489 4929.

Book Reviews

BUILDINGS FOR MUSIC

Michael Forsyth

Cambridge University Press, Cambridge 1985, 371 pp., ill, index, Price: A$107

This book fills an important gap in the Architectural Acoustics literature. It is not a text book on room acoustics and is therefore not a rival to the scientific approach of Cremer and Muller or of Kuttruff. It is closer to Beranek's "Music, Acoustics and Architecture", than it is to Doelle's "Environmental Acoustics" but it doesn't have a thesis to expound, or a philosophy to push.

Having said what the book isn't it is time to try and describe what it is. It is unashamedly an architectural history of rooms for western music. Because of the interlinking of music and architecture there is a significant amount of musical history in "Buildings for Music". The book covers the history of music and music rooms from the 17th century until 1982 and even speculates about future trends.

This book is essential for designers and consultants working on the acoustics of auditoria, not because it presents any theory but because it doesn't. Forsyth has amassed a superb collection of drawings and photographs of rooms for music and presents comments about how the buildings he describes were and are regarded. Designers can not only gain inspiration from this collection but they can put their own designs in context and, in a qualitative way, test their own pet theories using the drawings and descriptions presented. One such theory which could be tested and found wanting, using this book, is that of "spatial impression" being determined by lateral reflections.

What is also instructive are the comments of Charles Garnier, the architect of the Paris Opera House. "I gave myself pains to master this bizarre science (of acoustics) but . . . nowhere did I find a positive rule to guide me; on the contrary, nothing but contradictory statements . . . I must explain I have adopted no principle, that my plans are based on no theory, and that I have success or failure to chance alone . . . like an acrobat who closes his eyes and clings to the ropes of an ascending balloon". The adage that, "Good acoustics has as much to do with how well you see as with how well you hear", when taken with Garnier's comments tells us much about the usefulness of Forsyth's book compared with more scientific approaches.

"Buildings for Music" is a reference book on concert halls and opera houses which is very valuable and accessible. It should be read by anyone interested in music, acoustics and architecture.

Fergus Fricke

PHYSICAL PRINCIPLES OF MEDICAL ULTRASONICS
C. R. Hill (Editor)

Ellis Horwood Ltd., Chichester, 1986, pp. 495. Review copy from John Wiley & Sons Ltd., Aust. Distributor. Jacaranda Wiley Ltd., G.P.O. Box 859, Brisbane, Qld. 4001. Price: A$162.

Dr. C. R. Hill and his colleagues at the Institute of Cancer Research, Royal Marsden Hospital are well known for their pioneering contribution to the development of medical ultrasound. To write this book they have pooled their expertise with that of Dr. P. J. Fish, an authority on Doppler Techniques, and Dr. E. B. Miller to produce a volume which undoubtedly will become a classic on the subject and will be found on the shelf of all investigators working in the field.

The book comprises three sections. Part I addresses the physical principles involved in medical ultrasound. The first chapter describes the relevant concepts and methods of wave acoustics in a lucid descriptive manner in which mathematics is employed to illustrate but not hide the relevant principles. This is followed by two chapters which describe methods to analyse the structure of acoustic fields and techniques used to measure these fields. The next three chapters deal with physical properties of biological tissue which govern the propagation of ultrasonic energy in these media, determine the interaction mechanisms and influence the applications of medical ultrasound. These include the attenuation and absorption properties, the speed of propagation of ultrasound in tissue and the reflecting and scattering phenomena. Because of the complexity of the phenomena, the current methodology is based on the quasi-theoretical empirical approach. The chapters give a realistic appreciation of the problems involved, discuss the modern in vivo measurement techniques and summarise the published data on values of these parameters.

The second section of the book deals with the diagnostic applications of medical ultrasound. As the result of ultrasound investigations are presented generally in a form of images, the first chapter in this section discusses the characteristics of human visual perception. Pulse echo techniques and miscellaneous other imaging methods, such as transmission reconstruction imaging and acoustic holography, are then described followed by a chapter on tissue characterisation for which the authors use the term telehistory. The section concludes with a thorough description of Doppler methods which includes a comprehensive, theoretical analysis involved in the derivation of the Doppler spectrum.

The final section of the book discusses the bioeffects which can be obtained by ultrasound. The biophysics chapter deals with the phenomena which may occur during the propagation of ultrasound in biological media. These include thermal as well as non-thermal mechanisms, effects due to radiation pressure and acoustic streaming and a comprehensive discussion on various aspects of cavitation. This is followed by a chapter on therapeutic and surgical applications, whilst the final chapter examines the bioeffects which have been observed following irradiation of cells and organisms and possible implications of these when ultrasound is used to undertake diagnostic investigations particularly in obstetrics.

This book admirably achieves its aim of describing the physical principles which govern the applications of medical ultrasound. It contains a wealth of useful and relevant information supplemented by an extensive list of references in each chapter on major publications on the subject. I have no hesitation in recommending it to all physical scientists working in the field. It will certainly form a valuable addition to their library.

George Kossoff

Software for Analysis of Acoustic Noise by an IBM-PC

Supplied by M. B. & K. J. Davidson Pty. Ltd., 17 Roberna Street, Moorabbin, Victoria 3189.

Software developed by:—

Cirrus Research Ltd., Bridlington Road, Hunmanby (North Yorkshire), England. Y0140 PH.

Soeur-Anne S.A., 43, cours de la Republique, 69100 Villeaurbane, France.

The disc for review was supplied without any documentation: the initial dialogue on starting up simply gave the message that there were two demonstration programmes.

One programme was specifically for Leq calculations and operated on datasets already stored on disc providing histograms or all statistics associated with input data including L1, L10 and L95. The programme was generally fairly user-friendly with default conditions used by just pressing enter. The data files use very comprehensive header information so that they can be uniquely identified. The means of getting data into these files remains a mystery since no external documentation or explanatory information on the disc itself was provided. The customary READ ME file that one expects on an IBM PC-DOS disc was absent. It is disconcerting to review software which is designed to talk to the outside world by some interfacing when no details of the interfacing are provided.

A second programme provided a graphic display of a third octave analyser which gave maximum and minimum bars together with a moving cursor for each octave band which also could have the actual value in dB displayed. The display was well done and the prompts at the bottom which gave keystrokes to change the display were easy to understand. One option was supposed to allow the display to be dumped to printer but this did not function on the disc provided. Once again no information was provided on how the raw data was analysed into octave bands and then passed to the computer.

The software looks interesting but since no details on interfacing and pricing were provided it is not possible to make a final assessment of the product. If you want your IBM-PC (or equivalent clone) to be an Leq analyser or octave analyser with display then this may be what you want if you can discover by what mysterious ways the data get into the computer.

R. W. Harris

New Publications

Bradford Insulation
Building Insulation Design Guide

The extensive range of technical literature produced by Bradford Insulation has been expanded to include a **Building Insulation Series.**

The Bradford Building Insulation Series begins with two brochures detailing the Bradford Insulation product range, and includes technical data sheets on each building insulation product with product descriptions, applications, sizes and packaging information and technical test results.

There are also three application brochures, each with a detailed examination of specific Bradford Insulation applications namely 'Insulation for Houses', 'Insulation for Existing Buildings' and 'Insulation for Buildings — New Construction'.

The **'Building Insulation Design Guide'** completes the series with comprehensive information and data on the thermal performance of building elements and the effect of insulation on heat flow and condensation. The effect of solar radiation is also detailed.

The series offers application technology, product information and technical explanations on insulation for builders, architects, engineers, office management, government departments and commercial development companies.

Further information: Bradford Insulation office in your State.

Audio Engineering Society
Conference Proceedings

The Audio Engineering Society, an international organisation devoted exclusively to professional audio technology, has published The Proceedings of the AES 3rd International Conference: **Present and Future of Digital Audio,** Tokyo, Japan, 20-21 June, 1985, and The Proceedings of the AES 4th International Conference: **Stereo Audio Technology for Television and Video,** Rosemont, Illinois, 15-18 May, 1986. These two collections of original manuscripts, authored by leading audio professionals, are now available in bound form.

Further information: Audio Engineering Society, 60 East 42nd Street, New York, NY10165-0075. Prices: Members U.S.$25, non-members U.S.$35.

NEW PUBLICATIONS . . .

The following publications have been received by the Society and are held, temporarily, in the Acoustics Laboratory, School of Physics, University of N.S.W. They are available for inspection or loan by members. Photocopies (not in contravention of copyright conditions) may be ordered by contacting Cronulla Secretarial Services on (03) 527-3173. A charge will be made for photocopying and postage.

Acta Acustica
Vol. 11 Nos. 1, 2, 3 (1986)
Archives of Acoustics
Vol. 10 No. 2 (1985)
Applied Acoustics
Vol. 19 Nos. 5, 6 (1986)
Vol. 20 No. 1 (1987)

Contents include: **A. L. Brown and K. C. Lam,** Urban noise surveys; **T. D. Rossing and R. Perrin,** Vibrations of bells.

Vol. 20 No. 2 (1987)

Contents: **A. L. Brown** and **K. C. Lam,** Levels of ambient noise in Hong Kong; **A. Preis,** Intrusive sounds; **J. S. Mirza,** Learning English basic sounds through syllabic utterances; **P. R. Keswick** and **M. P. Norton,** A comparison of modal density measurement techniques.

Chinese J. of Acoustics (in English)
Vol. 5 No. 1 (1986)

Contents include: **Wang Hongzhang,** Acoustic transmission attenuation caused by random surface; **Wu Shuoxian,** A computer model for predicting the effects of motor vehicle noise on buildings adjacent to urban streets; **Li Changli** et al, A research on speech quality of channel vocoder; **Gong Xiufen** et al, Ultrasonic investigation of non-linear effect in biological medium; **Sha Jiazheng** et al, Frequency and efficiency of sound column at resonance.

Vol. 5 No. 2 (1986)

Contents include: **Ma Dayou,** Contributions to acoustics in China; **Zhu Weiqing,** Evolutionary spectra of non-stationary underwater sound reverberation process; **Rao Yu'an** et al, Normal values of human tympanograms; **Jiang Jinchang,** Structure and function of the sounding apparatus in cicada.

Vol. 5 No. 3 (1986)

Contents include: **Wang Hongzhang** et al, Measurement and calculation of electromechanical parameters of piezoceramic thin cylindrical tube transcenders; **Tao Duchun,** A study on ship-radiated noise rhythms (II); **Dai Genhua** and **Wang Hongyu,** Experimental investigation on the characteristics of diameter-expanded silencers.

Telecom Australia Research Laboratories, P.O. Box 249, Clayton North 3168
Review of Activities 1985-1986
Institute of Sound and Vibration Research
University of Southampton

Technical Reports Nos. 133 and 134
A design guide for visual displays and manual tasks in vibration environments.
Part I: Visual displays (Report No. 133), 33 pp.
M. J. Moseley and M. J. Griffin

SUMMARY: Design guidance relevant to the effects of vibration on visual tasks is provided. The information shows how effects are related to characteristics of the vibration, the display and other aspects of the environment. Published experimental studies are used as the basis of a series of design recommendations which may be used to minimise the influence of vibration on visual tasks.

Part II: Manual tasks (Report No. 134), 35 pp.
R. W. McLeod and M. J. Griffin

SUMMARY: Design guidance relevant to the effects of vibration on manual activities is provided. The information describes the mechanisms by which vibration may affect task performance and shows how effects are dependent upon characteristics of both the vibration environment and the task. Data from published experimental studies are used as the basis of a series of design recommendations which may be used to minimise the influence of vibration on manual tasks.

Technical Report No. 136, 57 pp.
S. J. Elliott and P. A. Nelson
The application of adaptive filtering to the active control of sound and vibration.

Technical Report No. 137, 124 pp.
L. C. Chow and R. J. Pinnington
On the prediction of oil layer damping on plates.

I. INCE Newsletters 42, 43, 44 (1986)

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C. AUTHOR INDEX

D. INTERVIEW

E. LETTERS

ADVERTISER INDEX

Readers are asked to mention this publication when replying to advertisements.

New Company

Ron Carr Associates Pty. Ltd. has been formed to continue and expand the business of Ron Carr and Company Pty. Ltd. The new company is a partnership between **Prof. Harold Marshall** and **Christopher Day** of Marshall Day Associates in New Zealand and **Peter Fearnside.**

Martin Beech-Jones, who worked for Ron Carr for three years, will join the new practice, which is located at 22 Trafalgar Road, Camberwell, Victoria 3124. Phone 882 7288. Fax 882 6277.

FUTURE EVENTS —

● Indicates an Australian Conference

1987

May 11-15, INDIANAPOLIS

MEETING OF ACOUSTICAL SOCIETY OF AMERICA
Details: Mrs. B. Goodfriend, A.S.A., 335 East 45th St., New York, NY 10017, U.S.A.

May 13-15, POLAND

IV SYMPOSIUM ON HYDROACOUSTICS
Details: Dr. R. Salamon, Institute of Telecommunication, Gdansk Technical University, ul Majakowskiego 11/12, 80-952 Gdansk, Poland.

May 19-21, POLAND

INTERNATIONAL CONFERENCE.
"Prospects in Modern Acoustics, Education and Development."
Details: Prof. Dr. A. Sliwinski, University of Gdansk, Institute of Experimental Physics, 80 952 Gdansk, Wita Stwosza 57.

● May 20-27, MELBOURNE

MAINTENANCE ENGINEERING CONFERENCE 1987
"Effective Maintenance: the road to profit"
Details: Institution of Engineers, 11 National Circuit, Barton, A.C.T. 2600.

June 1-4, YUGOSLAVIA

XXXI ETAN CONFERENCE
Details: Prof. P. Pravica, Electrotechnical Faculty, Bulevar Revolucije 73, Belgrade, Yugoslavia 11000.

June 8-10, PENNSYLVANIA

NOISE-CON 87
"High Technology for Noise Control".
Details: Conference Secretariat, NOISE-CON 87, The Graduate Programme in Acoustics, Applied Science Building, University Park, PA 16802.

June 9-11, UMEA, SWEDEN

4th INTERNATIONAL MEETING ON LOW FREQUENCY NOISE AND VIBRATION.
Details: Dr. W. Tempest, Multi-Science Publishing Co. Ltd., 107 High St., Brentwood, Essex, CM14 4RX, England.

● June 17-19, BRISBANE

COMPUTING SYSTEMS CONFERENCE 1987
Details: Institution of Engineers, 11 National Circuit, Barton, A.C.T. 2600.

June 19, MADRID

ACOUSTICS AND OCEAN BOTTOM
Details: SEA - FASE 87, Calle Serrano, 144, Madrid 6, Spain.

June 22-26, SEATTLE

INTERNATIONAL SYMPOSIUM ON FISHERIES ACOUSTICS
Details: M. O. Nelson, Div. Resource Assessment & Conservation Engineering, U.S. National Marine Fisheries Service, 7600 Sand Point Way NE, Bldg. 4, Seattle, Washington 98115-0070.

June 23-25, LISBON

5th FASE CONGRESS
Details: SPA - FASE 87, Lab. Nac Engenharia Civil, Av. Brasil, 1799 Lisboa Codex, Portugal.

July 6-9, LONDON

ULTRASONICS INTERNATIONAL CONFERENCE AND EXHIBITION
Details: M. Vukovojac, Butterworth Scientific Ltd., P.O. Box 63, Bury Street, Guildford, Surrey GU2 5BH, U.K.

● July 8-10, BATHURST

ANZASCA CONFERENCE
"Controlling the Environment."
Details: Ann Heydon, Dept. of Architecture, University of Sydney 2060.

July, ANTWERP, BELGIUM

15-25, SUMMER SCHOOL ON INTERNAL FRICTION PROCESSES.
27-30, CONFERENCE ON INTERNAL FRICTION AND ULTRASONIC ATTENUATION IN SOLIDS.
Details: R. de Batist, S.C.K. — C.E.N., Boeretang 200, 2400 MOL, Belgium.

August 24-28, U.S.S.R.

11th INTER. SYMPOSIUM ON NON-LINEAR ACOUSTICS
Details: V. K. Kedrinskii, Lavrentyev Institute of Hydrodynamics, Lavrentyev Prospekt 15, 630090 Novosibirsk.

September 8-11, POLAND

XXXIV OPEN SEMINAR ON ACOUSTICS
Details: Inst. of Telecommunication & Acoustics, Wroclaw Techn. Univ., Wybrzeze Wyspianskiego 27, 50-370 Wroclaw.

September 13-16, BIRMINGHAM

CONFERENCE OF BRITISH SOCIETY OF AUDIOLOGY
"Aspects and Implications of Hearing Impairment Throughout Life."
Details: Mr. N. Bland, Centre for the Hearing Impaired, Western Road, Birmingham, B16 7QQ, U.K.

September 15-17, CHINA

INTER-NOISE 87
"Noise Control in Industry".
Details: Inter-Noise 87, 5 Zhonggvancun St., P.O. Box 2712, Beijing, China.

September 22-25, WARWICK

NEW MATERIALS AND THEIR APPLICATIONS
Details: Meetings Officer, Institute of Physics, Belgrave Square 47, London SW1X 8QX, U.K.

October 5-9, CZECHOSLOVAKIA

NOISE AND ENVIRONMENT
Details: Dom Techniky Csvts, Secretariat 26, Akustickej Konferencie, Skultetyho, ul 1, 832 27 Bratislava, Czechoslovakia.

● November 12-13, HOBART

ACOUSTICS IN THE EIGHTIES.
Details: Stephen Samuels, A.A.R.B., P.O. Box 156 (Bag 4), Nunawading, Vic., 3131.

November 16-20, MIAMI

MEETING OF ACOUSTICAL SOCIETY OF AMERICA
Details: Mrs. B. Goodfrend, A.S.A., 335 East 45th St., New York, NY 10017, U.S.A.

● December 1-4, LAUNCESTON

8th AUSTRALASIAN CONFERENCE ON COASTAL AND OCEAN ENGINEERING.
Details: Conference Manager, Institution of Engineers, 11 National Circuit, Barton, ACT, 2600.

1988

● January 25-29, SYDNEY

BICENTENARY CONGRESS OF PHYSICISTS
Details: Dr. Collocott, CSIRO Division of Applied Physics, P.O. Box 218, Lindfield 2070.

March 15-17, GERMANY

DAGA '88
Details: R. Martin, Abt. 1-Mechanik and Akustik, Bundesalle 100, D-3300 Braunschweig.

May 16-20, SEATTLE

MEETING OF ACOUSTICAL SOCIETY OF AMERICA
Details: Mrs. B. Goodfriend, A.S.A., 335 East 45th St., New York, NY 10017, U.S.A.

June 6-10, YUGOSLAVIA

XXXII ETAN CONFERENCE
Details: Prof. P. Pravica, Electrotechnical Faculty, Bulevar Revoluci je 73, YU-11000 Belgrade.

August 21-25, STOCKHOLM

5th INTER. CONGRESS ON NOISE AS A PUBLIC HEALTH PROBLEM
Details: Noise '88, C/- Reso Congress Service, S-113 92 Stockholm.

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