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A.A.S. ACTIVITIES

TECHNICAL MEETINGS

NEW SOUTH WALES

The N.S.W. Division enjoyed a very interesting technical meeting when it was addressed, on July 19th, by Professor A.A. Williams, Jnr., Brown University, U.S.A.

Dr. W.F. Hunter reports:

Many practical estimates or decisions are made, in ordinary life, on the assumption of a linear world -- i.e., one governed by simple proportionality, etc. The analysis is easy and the results are often successful. Even in rigorous mathematical science, much the same is true, and for the same reasons. Among the laws of physics that are usually accepted as linear are Maxwell's equations of electromagnetism, and the equation governing acoustical waves. Nevertheless, the field of nonlinear optics exists, because the optical properties of some materials are nonlinear, and powerful light beams from a laser reveal these nonlinearities. More fundamentally, Maxwell's laws are affected by a gravitation field, which alters the metric of space, so that in principle nonlinear interactions should exist between electromagnetic and gravitational waves.

Nonlinearity is just as pronounced in acoustics. The three governing equations -- of continuity, motion, and state of medium supporting a sound wave -- are nonlinear. Only neglect of the nonlinear aspects can lead to the linear wave equation that governs most of acoustics. Consequently, linear acoustics is valid, strictly, only for infinitesimal changes in the pressure, density and particle velocity of the supporting medium.

The deviation from linear acoustics can be demonstrated qualitatively by considering a sound wave in an ideal gas that follows the adiabatic gas law. That is, the Equation of State is accepted as nonlinear, while the Equations of Continuity and of motion are regarded as linear. The outcome is a prediction that regions of greater compression in the sound wave travel faster and regions of greater rarefaction travel slower, with respect to the linear sound speed of infinitesimally weak sound waves.

These differences in speed are usually small, but their effects are cumulative in time, measured in reciprocal frequency, and in distance travelled, measured in acoustic wavelengths. For example, an initially sinusoidal sound wave of single frequency will progressively "steepen" its wave fronts, as compressions overtake rarefactions; it may approach the form of a periodic succession of shock fronts, somewhat like ocean waves approaching the stage of "breaking". According to Fourier's theorem, such a progressively distorted wave must be described by an infinite series of all the harmonics of the original single frequency, with the admixture of higher harmonics progressively increasing. Therefore the acoustic beam acts as a long "end-fire array" that by nonlinear "self-scattering" produces harmonic frequencies not present in the initial sound wave. If this initial sound wave contains two or more components of different frequencies, all the harmonics of each frequency are generated, and so are all the "sum tones" and "difference tones" of all harmonics.

In 1963, P.J. Westervelt showed theoretically that an initial sound wave containing two frequencies f1 and f2 would, in particular, produce a difference-frequency component lf1 - f2l could be conventionally produced only by a very large -- even impractically large -- source. Second, this low-frequency beam experiences low absorption and thus can persist for long distances. Third, the band-width of the difference-frequency beam is very great, which means that much information can be impressed upon it, by amplitude-, frequency-, or pulse-modulation. A practical application is already in use: bottom-mapping sonar, in the ocean. The difference-frequency beam can reach and echo back from great depths; the sharp focusing of the beam allows mapping of small details; and the beam penetrates some distance into the ocean bottom and reveals its structure to the geophysicist.

Another application - also suggested by Westervelt - is in the stage of applied research and testing. A weak beam of low-frequency sound from a distance source can be directionally detected, in principle, via nonlinear interaction with a strong, sharply focused beam at high frequency. The latter beam acts as an endfire array, producing the sum and difference frequencies, which can be detected.

Finally, Westervelt has recently proposed use of a powerful laser beam, amplitude-modulated at some low acoustic frequency. Localized heating of the medium should produce a sharply focused acoustic beam at the modulation frequency. This example of nonlinear interaction between electromagnetic and acoustic waves is now in the early stages of experimental testing.

VICTORIA

Members and visitors were shown over the Studios of Bill Armstrong and his staff, and each member present also received a duplicated sheet giving a brief outline of the Company and its activities.

Graeme Harding reports:

From a small studio in 1965, Bill Armstrong's studios have grown to occupy their present building of 97,000 sq. ft. floor space. Currently, they are using about one-quarter of the building floor space and have ample room for expansion. The building was a large grocery warehouse, now converted with studios built into the open floor space, and having an air of spaciousness about them.

The whole emphasis and aim of the studios has been to provide a creative atmosphere for the artists; one that is comfortable to the artist and less tiring for long recording sessions. The vivid colours and bold outlines provide the "with it" look which the artists find attractive. The studios have produced eight gold records including the well-known disc, "Sadie the Cleaning Lady".

The work of Bill Armstrong's studios can be divided into three types:

Commercial advertising
Recorded music
Visual aids

Whilst commercial advertising forms the backbone of the work, and probably earns the most revenue, both the recorded music and visual aid components are increasing as a proportion of the total work activity. The visual aid work consists of the preparation of voice commentary and music for documentary films and slide programmes.

During the visit the four studios in current use and the associated control room were inspected.

Studio 1 is a large rectangular studio measuring 44' x 62' x 16', finished in blue and purple with a volume large enough for an orchestra or large music groups. At the time of the inspection, a vocalist was experimenting with different vocal expressions so that the sound best suited to the theme of the advertiser could be selected and recorded.

Studio 2 is a smaller rectangular studio, and the control room is equipped with a 16-track tape recorder used to record separately the various instrumental groups within an orchestra, with the strings recorded separately and playing to the music of the rest of the orchestra. This allows a final tape to be made in which the balance between all the orchestral instruments may be selected to provide the best sounding music.

Studio 3 was still in the process of construction at the time of the visit.

Studio 4 was hexagonal in shape and finished in bright purple. In the control room of this studio an operator demonstrated the cutting and splicing of tape. All were intrigued by the way this was done, bearing in mind that after a section of the tape is cut out, the music must have continuity, and the beat or rythm in the music has to remain unbroken.

Studio 5 is a circular studio finished in orange, intended principally for vocal and commentary.

Finally, members and visitors moved to a large room on the 3rd floor of the building and were given a demonstration of a 4-channel sound system and shown the results of some of the impressive work done by the studios in visual aid techniques.

At the conclusion of the meeting, Bill Armstrong and Mr. Thirkell, from Optronics Pty. Ltd., manufacturers of the 16-track tape-recorder used by the studios, were pleased to answer questions put to them by those present. Particularly intriguing to the members was the remarkable performance of the 16-track tape-recorders with an unweighted signal to noise ratio of 70 dB, and matters concerning studio acoustics and microphone techniques.

NEWS AND NOTES

NOISE STUDIES AND SYSTEMS ENGINEERING

C.S.I.R.O. - Division of Mechanical Engineering,
Highett, Victoria.

D. Gibson reports:

Sound and vibration studies are being undertaken in order to understand and reduce the noise from refrigeration compressors.

A compressed air driven fan has been developed for use in the Australian Mining Inustry. This work was sponsored by the Australian Mineral Industries Research Association. The production prototype fan is more efficient and will be subjectively judged about half as noisy as the commercial fan it is designed to replace. The prototype fan is now undergoing field tests at Mount Isa Mines Ltd.

The sound produced by air flow through heat exchanger coils has been assessed. The accumulated noise data has been correlated as a function of face velocity, and a report on the study is being prepared for distribution throughout the air conditioning industry.

A Noise Survey is being made by consultants, King, Sawley and Associates Pty. Ltd. by contract with the CSIRO Division of Mechanical Engineering, to examine the nature and extent of the problem of noise generated in pipelines in some of the process and manufacturing industries, with a view to defining more clearly the optimum method of attacking the problem at its sources.

The noises generated by a rotary lawn mower are being studied with a view to making a reduction in the noise level. The problem is more severe with models provided with grass catchers.

PLUMBING NOISE

The Society commends the interest shown recently regarding noise from plumbing.

The Institute of Plumbing Australia, W.A. Chapter, conducted an evening seminar, "Noise Pollution in Plumbing" on 12th September, at the West Australian Institute of Technology.

The Institute of Plumbing, Australia, N.S.W. Chapter, and the Master Plumbers & Sanitary Engineers' Association of N.S.W. plan an evening talk on Plumbing Noise, to be held in October. Final date is yet to be fixed.

R.A.N. SYMPOSIUM

A symposium on "Communications" will be held during October/November. Enquiries to Dr. M. Hall, 32-2211.

NATIONAL CONVENTION - MELBOURNE

Noise is an important aspect of present and future transportation, and hence takes its place among the subjects to be discussed at a large conference scheduled for the end of October. The Society of Automotive Engineers - Australasia has set as the theme for its 1973 National Convention, "Responsibility in the Automotive Industry". The Convention is to be held at the National Sciences Centre, in Melbourne, from Monday, 29 October to Friday, 2 November 1973, both dates inclusive.

Mr. Marshall Green, U.S. Ambassador to Australia, and the Honourable Mr. C.K. Jones, Australian Minister for Transport, will be among the speakers on the opening day of the conference, which will be officially opened by the Honourable Mr. R. J. Hamer, Premier of Victoria. Papers will be presented in the technical sessions on sociological aspects, future city transport, and safety. The theme, "Emission and Noise", set down for Thursday, 1 November and Friday, 2 November, extends over 2 days of the 5-day conference.

Details of the conference, which includes visits to various manufacturing and testing organisations as part of the programme, are obtainable from the SAE, National Science Centre, 191 Royal Parade, Parkville, Victoria.

NOISE CONTROL COURSE - ADELAIDE

The Departments of Mechanical Engineering and Adult Education of the University of Adelaide are conducting an intensive course in Noise Control from Monday, 22 October to Friday, 26 October 1973. The course is intended primarily for professional engineers and others in industry who are faced with practical problems of noise reduction and control. There will be approximately 20 hrs. of lectures and

15 hrs. of laboratory demonstrations and practical measurements. The topics will include:

Wave propagation in fluids and solids.
Scales for noise measurement.
Measuring equipment.
Noise level criteria.
Noise survey techniques and interpretation of measurements.
Noise transmission.
General principles of noise reduction.
Noise reduction in existing situations.
Use of enclosures, mufflers, and ear protection.
Equipment noise specifications.
Emphasis will be placed on noise survey procedures, and procedures for drawing up noise specifications for new equipment.

The lecturers for the course are Dr. D.A. Bics, Dr. G.L. Brown, Dr. M.K. Bull, and Dr. J. M. Pickles, of the Department of Mechanical Engineering in the University of Adelaide, and Mr. R.B. King and Mr. M. Pryce, Consulting Acoustical Engineers, and Mr. R.C. Stafford, Scientific Officer of the Occupational Health Branch, South Australian Department of Public Health.

The fee for the course, including a week of lectures, and additional notes and materials to be issued to those attending, is $100.

NOISE, SHOCK AND VIBRATION CONFERENCE - MONASH, 1974

There has been an excellent response, both locally and internationally, to the Call for Papers for the Noise, Shock and Vibration Conference, Monash University, 22 - 25 May 1974.

The Conference promises to be one of the outstanding gatherings of 1974 for those interested in the causes, effects and measurement of impulsive of continuous noise and vibration. It is to be held under the joint sponsorship of Monash University (Department of Mechanical Engineering), the Australian Acoustical Society (Victoria Division) and The Institution of Engineers, Australia (National Committee on Applied Mechanics). International authorities have accepted invitations to present papers - Dr. Leo Beranek has agreed to give the opening address.

Persons seeking information about the Conference should write now to :-

The Secretary
1974 NSV Conference
Department of Mechanical Engineering
Monash University
Clayton 3168 VICTORIA
AUSTRALIA

ENGINE EXHAUST MUFFLERS

R. J. ALFREDSON

Monash University
Clayton, Victoria

SUMMARY

A brief review is presented of theoretical methods used for designing multi-cylinder internal combustion engine exhaust mufflers.

INTRODUCTION

The advantages of using theoretical methods for designing exhaust mufflers are clearly obvious. However, the accuracy that is generally obtained is not very impressive and consequently the techniques that are widely used today for muffler design are 'partly theoretical and largely empirical', Ref. (1).

It is proposed therefore to review briefly some of the different theoretical approaches available for multi-cylinder exhaust mufflers and to indicate possible reasons for their poor performance. Interest is centred on

(a) Shock Tube Method,
(b) Method of Characteristics, and
(c) Acoustic Method.

Finally mention is made of a new linearised approach that has been successfully used with a number of different engines.

SHOCK TUBE METHOD

In the shock tube method it is assumed that the pressure fluctuations produced in the exhaust manifold during exhaust valve opening are sufficiently high to produce steepening of the waveform and eventually travelling normal shocks appear in the exhaust system. The muffler is designed to attenuate these shocks.

This approach to muffler design was first suggested by Davies (2) and later extended with Dwyer (3). Theories were developed which accurately predicted the attenuation of a shock as it traversed a typical exhaust system.

Mufflers designed on this basis were tested on multi-cylinder engines with only partial success. It was concluded that steepening of the pressure waveform was slight and thus wave action rather than shock action dominated the exhaust system (4). Resonance behaviour was associated with this wave action and this could not be ignored. The shock approach seems to be of limited value for multi-cylinder engine muffler design.

METHOD OF CHARACTERISTICS

The method of characteristics is a non-linear technique which allows the behaviour of finite amplitude pressure waves in a pipe to be calculated under a large variety of flow conditions. The basic concepts are discussed fully in several standard texts, e.g. (5) (6).

Originally the method of characteristics relied on graphical procedures (7), but more recently it has been computerised and substantially developed due largely to the influence of Benson, e.g. (8). The major interest has been in gas exchange processes, and the release of pressure from cylinders. Calculations can commence with the exhaust valve just beginning to open and this provides a realistic boundary condition for the exhaust system calculation and allows also the evaluation of the effect of the exhaust system on the engine's performance.

There has been little enthusiastic support of th use of the method of characteristics for muffler design The major handicap is cost, since even with the latest generation of fast computers, many hours of computation would be involved for a typical muffler. Computer speeds will undoubtedly increase as years pass and this method will eventually become very attractive. For the present it remains an uneconomic proposition.

ACOUSTIC METHOD

The acoustic method is the oldest and best established theoretical method for designing exhaust mufflers. It is assumed that the total exhaust system behaves as an acoustic transmission line.

Numerous reports on the application of acoustic techniques to muffler design occur in the literature. Perhaps the most comprehensive is that due to Davis et al (9). As a result of tests using a loud speaker as signal source Davis drew up design charts and produced several exhaust mufflers for a helicopter engine. The performance of these mufflers was less than expected and Davis concluded that research into muffler performance under realistic exhaust conditions was needed.

While the assumption of small pressure fluctuations is of course universal with this approach, there is a tremendous variation in the other assumptions made by the various authors. To illustrate this let us consider just one component of the exhaust system, namely the tail pipe.

Tail Pipe Performance

At least 4 different assumptions occur in the literature concerning the vehaviour of the pressure fluctuations at the tail pipe outlet; - These are

(a) Reflection coefficient zero, (9);
(b) Reflection coefficient unity, (10);
(c) Reflection coefficient given by acoustic theory for sound radiating from an unflanged pipe (11), e.g. (12);
(d) Infinite transmission line (13).

Each of these assumptions predicts a different level of sound radiated by the exhaust system. The differences are substantial; for example, assumption (a) implies all sound incident in the tail pipe is radiated while assumption (b) claims that none is radiated at all!

Similar examples of gross differences in assumptions could be given for other sections of the exhaust system. It became apparent some five years ago that the reason for the poor performance attributed to the acoustic theory might not be the assumption of small pressure fluctuations but rather the numerous other assumptions which were largely not proven. This has led to a modified linearised approach.

MODIFIED LINEARISED METHOD

A systematic investigation was undertaken using the exhaust system of a 2 stroke 6 cylinder diesel engine which developed about 250 bhp. This engine was known to have a serious exhaust noise problem.

The performance of each component of the exhaust system was examined in turn and theoretical models developed on the basis of these tests. The total performance of the complete system was then obtained by combining the various components in sequence. It is not intended to discuss the results in detail since these are given elsewhere (14) - (16) but rather to indicate the more important findings.

(1) The maximum pressure fluctuations were of the order of 1 to 2 lb./in.^{2} and these occurred at frequencies around 250 Hz. Steepening of pressure waveforms was not important.

(2) The mean gas flow has a significant effect on the transport of acoustic energy (17). It's neglect will lead to erratic and generally over-optimistic attenuation predictions.

(3) Adiabatic rather than isentropic conditions apply at area expansions.

(4) The magnitude of the pressure fluctuations produced at the exhaust manifold is not significantly affected by the exhaust system for many multi-cylinder engines.

(5) The effect of the exhaust system on multi-cylinder engine performance is generally small for normal exhaust systems.

(6) The total performance of an exhaust system can be predicted with reasonable accuracy by combining the theoretical models in sequence. A few seconds of computer time were generally needed to predict the exhaust system performance on a digital computer. The design of an optimum muffler involving the systematic evaluation of a large number of different mufflers takes from 15 to 30 minutes for a typical muffler.

The method has been used on several occasions to design mufflers for a number of multi-cylinder engines. While it has been possible to check only 3 designs in detail, all mufflers have been successful. The three designs that were carefully evaluated were found to be within ± 3 dBA of the predicted attenuations which were 20 dBA, 25 dBA and 30 dBA respectively.

CONCLUDING REMARKS

It appears at this stage that the linearised approach outlined above represents the best compromise between accuracy and time required on a digital computer. It resulted firstly from a survey of existing theoretical methods for designing mufflers (particularl the questioning of assumptions made with the traditiona acoustic approach) and secondly from a systematic investigation made in a real exhaust system. It should be noted, however, that while the approach has been successful with a number of different engines it is still in its early stages of development and considerably more research still remains to be done.

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MEASURING SOUND ABSORPTION

R. C. DONNAN

Hardboards Australia Ltd
Sydney

SUMMARY

A case is made for using one standard Code in Australia for the determination of the sound absorbing properties of building materials.

* * *

Australian manufacturers of ceiling products and some acoustical consultants have been concerned for several years about dual standards used by suppliers of these materials in testing and reporting sound absorption qualities. Some doubt and confusion has consequently arisen about the relative performances of local products when compared to those of some imported products.

Comparative measurements recently carried out in reverberation rooms in Australia and in U.S.A., according to the standard codes of each country, have not only disclosed apparently significant and consistent differences between the results from the two sources, but that the U.S.A. acoustical laboratory tests gave the consistently higher figures.

Since there is an increasing awareness in the building industry of the importance of noise control, the sound absorption quality of ceiling products has become one of the important criteria influencing the decision of designers and consultants in making final recommendations for ceiling product specifications. In the market place, the product manufacturer publishing sound absorption data derived from a source which gives highest figures thus will have a distinct selling advantage.

The discrepancy between the results from the two testing procedures was suspected initially as a result of impedance tube tests carried out intermittently, but over a long period.

These test results showed smaller differences between the sound absorption properties of ceiling materials from local and American sources than was indicated by the published figures. This led to an exchange of views about testing standards between a NATA approved testing organisation here and one of the well known acoustical laboratories in the U.S.A. As a result of this discussion, two batches of felted mineral fibre based acoustical ceiling panels were tested in both countries.

The first batch, panels of U.S.A. origin random collected from two cities in Australia, was tested here prior to sending to the American acoustical laboratory during 1972. Some months later - early in 1973 - a similar cross check was repeated with Australian produced ceiling panels. Table 1 shows the results.

TABLE I

Acoustical Panel Source	Test Authority	Absorption Coefficients at indicated frequency - Hz						
		125	250	500	1000	2000	4000	NRC
U.S.A. Manufacturer	Aust. (1)	.20	.28	.46	.68	.79	.78	.55
	U.S.A. (2)	.36	.38	.50	.76	.87	.89	.63
Australian Manufacturer	Aust.	.26	.20	.51	.68	.68	.69	.52
	U.S.A.	.25	.29	.60	.81	.81	.80	.63

There are several differences between the two standard test procedures, known to people in the acoustical profession, which may account for the different results, but while it is partly the purpose of this article to focus attention on them, it is outside our competence and the scope of this article to make further comment here.

The matter discussed above was formally brought to the attention of the Australian Acoustical Society by the author of this article, including the tabled test data relating to the acoustical panels of U.S. origin. The second set of results was not then available.

Help and advice was sought from the Society and here we quote two paragraphs of the letter -

> "We ask your help, as the professional body most directly concerned with acoustical science in Australia, in suggesting how an equitable basis for the rating of acoustical products sold on the Australian market could be established and disseminated amongst those specifying acoustical materials.
>
> Would it be proper to suggest that the basis for rating acoustical products supplied against acoustical consultants' specifications, or to meet government or statutory requirements, or supplied against a tender, shall be the Australian standard?"

We reaffirm these views and acting on part of the helpful advice we received from the N.S.W. Division of the Society, we have prepared this article so that a more "equitable basis" for comparison of product qualities may hopefully be recognised and insisted upon by the specifiers and selectors of acoustical products."

MEASUREMENT

J. A. IRVINE

Carr & Wilkinson, Consultants
Sydney

SUMMARY

Making measurements of one kind or another is so commonplace to all of us that the basic elements are often quite forgotten. It is the purpose of this article to consider briefly the history, principles and practice of measuring, with a view to providing some reminders of what it is all about.

HISTORY

Going back 5000 years, we find well established systems of measurement being used, for instance by the Egyptians. They had the 'cubit', a unit of length, whose value in our terms was about 20½ inches. It was used from the time of the predynastic tombs. Then, for measuring capacity, they had the 'hen', of some 29 cubic inches, and for weight the 'shoti', equivalent to about 8 grams. It is clear that all these measures were derived from earlier versions; the modern practice of measurement has a very long history behind it.

Even so far back as Egyptian days, what might be called 'international standards' must have been used. There has been noted a quite definite agreement on measures as between the Egyptians, Assyrians and other nations of that time. This obviously arose from the needs of trade. Such needs have increased, rather irregularly it must be admitted, until the present day, when elaborate and highly precise systems are available, all over the world, for measuring virtually anything in a way meaningful to everyone.

The industrial revolution was a key factor in forcing the development of precise measurement. Whereas prior to the days of mass production, goods were created from pieces each made individually to fit into the place awaiting them in the growing article, machine manufacture changed this completely by turning out hundreds or thousands of pieces ahead of the assembly stage. This meant, of course, that the machine-made pieces needed to be very consistent in their measurements if they were to fit at the time of assembly. A further need arose from the growing practice of repair by replacment of worn or faulty parts. For this to be successful, it was clearly necessary that 'spare parts' must be made carefully, and the place into which they were to fit in the article awaiting repair must also be held to pretty constant dimensions.

As a result of growing needs, two establishments came into being at the start of the present century to assist with the problems of measurement. These were the National Physical Laboratories in England (1900) and the National Bureau of Standards in the United States of America (1901). Other countries followed suit, and work proceeded along truly international lines from that time to the present.

PRINCIPLES

Some consideration of the basic philosophy of measurement is a valuable exercise.

First, just what do we mean by this word "measurement"? It could be stated that "to measure" is to compare a material property with an agreed standard. The Concise Oxford Dictionary defines measure as "ascertain extent or quantity of (thing) by comparison with fixed unit or with object of known size."

Clearly, there are at least three essential elements involved; a 'comparison', a 'standard' and an 'observer'. There is in fact though, another equally essential element to be recognised, which may be called 'error'. As used here, 'error' means that unavoidable random difference between successive measurements of a property of a given object. The word does not, of course, include what are ordinarily known as 'mistakes'.

The Encyclopaedia Britannica, 1961 Edition, has interesting comment to make, and we can hardly do better than to quote from it.

"MEASUREMENT. It is perhaps only over the last 100 years that the matter of international standards has been taken seriously.

Units and Standards of Measurement. It is important to distinguish between units and standards of measurement. The process of measuring any quantity consists essentially in ascertaining the ratio of that quantity to another fixed quantity of the same kind, known as the unit of that kind of quantity.

A unit is essentially an abstract conception and cannot be utilised as a basis of measurement until it has been defined in one of two ways: by reference either to arbitrary material standards, or to natural phenomena, including in the latter physical constants and the properties of specified substances. For example, in the metric system the unit of length is defined by the separation of two lines on a particular metal bar, but is likely to become referred to a certain number of wavelengths of a particular spectrum line; the unit of mass, once the mass of a certain volume of water, is now the mass of a particular cylinder of platinum-iridium. The unit of time has long been defined by reference to natural phenomena, and temperature is scaled by reference to certain natural temperatures, such as the triple point and boiling point of water.

Some kind of comparison is always involved when a measurement is made. This is usually accomplished by comparing the quantity to be measured with a standard whose value is known in terms of the unit of that quantity, although the presence of the standard in any particular measuring instrument may not be so easily recognised as it is in instruments described as 'comparators'. The standard in its turn must have its value ascertained in terms of the unit; this is ultimately the duty of the Standards laboratory.

Random and Systematic Errors. No measurement is ever absolutely correct; some degree of experimental error is always present. Experimental error may be random or systematic. Random error is mostly due to uncontrolled and erratic minor disturbances of the conditions; e.g. temperature, in which any given measurement is conducted. Such disturbances lead to a series of observed values having, for instance, a Gaussian distribution about the true value. The extent to which the reliability of the final result is affected by random errors can then be readily assessed, by well-established methods of statistical analysis.

It is possible in principle for a measurement to be free from significant random error and yet be subject to an appreciable systematic error which, by reason of its elusive nature remains undetected. Only by rigorous examination of all the processes involved in a measurement can the possible sources of systematic error be traced and steps taken to eliminate or evaluate them. For instance, where an observer has a physiological bias in the interpretation of readings it can often be arranged that the bias operates an equal number of times in opposite directions. Evaluation of systematic error is best done by the observer himself from his personal knowledge of all the experimental conditions in which his measurements are made. The most satisfactory way of assuring that the measurement of a physical standard or constant is free from unsuspected systematic error is to make two or more determinations by entirely different methods, if possible in different laboratories, and with different observers. If each determination gives the same result within the limits of the independently assessed experimental errors, then the probability is that the major systematic errors have been eliminated, on the assumption that the causes of systematic disturbance are unlikely to be the same in the various experiments."

PRACTICE

Some examples from the ordinary practice of measurement will give relevance to the principles discussed above.

SIMPLE CASES

Let us take an ordinary length measurement, as made by a carpenter. This would usually be made with a folding three foot rule. The precision required for most of this kind of work is around about ± 1/16 inch, and readings to this order can easily and with considerable certainty be made with most such rules.

It may be asked, then, why any further consideration need be given to the matter?

At least two significant points arise: how is it known that there is adequate agreement between the length of the 'three foot rule' and that distance known as the 'standard yard', and further, has wear in the hinges or elsewhere caused the rule to develop error with use? Perhaps the second point may be dismissed with the remark that any responsible carpenter would throw away such a worn and faulty rule before errors become significant in his class of work. But the first source of error is one which cannot be detected by simple inspection.

How indeed does the conscientious carpenter deal with the problem? In general, he buys his rule from a manufacturer with a reputation for good quality control; i.e., he relies upon a higher authority (the manufacturer) to have established a system by which the accuracy of his product is controlled to within the desired limits. And this system is in turn held in a sufficient state of accuracy by occasional reference to a national standard, either directly or through substandards.

In this simple case, although reference is actually made to the national standard, nevertheless there is not a continuous train of reference from the particular measuring device right through to the ultimate standard. Nor is there any great need, because the degree of accuracy demanded is an easy one for any reputable manufacturer to provide.

Another interesting example might be that of a typical engineer's micrometer, measuring distances in thousandths of an inch. Here it is the practice to supply with the instrument a test piece, guaranteed by the manufacturer to be within some appropriate tolerances of a stated dimension. This test piece is used at intervals to check the accuracy of the micrometer, and together with the use of a zero reading, such a procedure is generally regarded as being sufficient to prove that the instrument is reliable for measurements within its designed range. Here we have, in effect, a train of reference right from the particular measuring device up to the national or international standard of length. Reputable manufacturers have the competence to make their guarantee of the test piece a reality; they do have proper quality control and reference through sub-standards to the national or international standards. Even here, though, errors can arise which cannot readily be detected. For one, the consistency of graduation, between zero and the dimension of the test piece, can only be inferred from the reputation of the manufacturer. Of course, use of a range of test pieces would reduce the risk of error from this source, though such a procedure is not usually followed. Wear of the screw thread of such micrometers must eventually occur, and will often be found to vary from one end of the scale length to the other, depending upon the actual measured lengths most commonly determined. Only by tests at various scale values could this error be detected; the lubricant normally present on the internal thread of the micrometer makes it almost impossible to detect wear by a feeling of 'looseness'.

From the two examples quoted above, it will be clear that as the tolerances in measurements become smaller, the need for more elaborate testing of the equipment tends to become greater.

MORE COMPLEX CASES

Some kinds of measurement, however, involve devices whose constancy of performance is much below that of foot rules and micrometers. In these cases it is not unusual to find that while the acceptable tolerances, expressed as a percentage of the actual value measured, are relatively large, the normal 'drift' or change in performance of the equipment is such that frequent and often quite elaborate testing is needed in order to keep within these tolerances. Such a state of affairs is often, though not exclusivel found in electronic devices. When faced with these problems it is not sufficient to rely upon the reputation of the manufacturer. However conscientious he may be, the present "state of the art" does not allow him to avoid risks of error from these sources. A common problem with electronic instruments is that known as 'noise'. This is the total of all the minor, often random, pseudo signals caused by various circuit elements. The ratio of the true signal to 'noise' governs the amount by which the sensitivity of a given piece of equipment may be improved by a rise in amplification. A common example is that of a radio signal competing with static; if the signal/noise ratio is insufficient, no amount of extra volume will render the signal intelligible.

Acoustical measuring equipment includes items which come into these latter categories; many devices are subject to both 'drift' and 'noise'. Furthermore, the actual measurements tend to be highly sophisticatec demanding a complex array of critical components withir the one piece of apparatus. Because of these complications, it is generally necessary to create several trains of reference from the particular item of equipment to the national (and international) standards.

Diagram 1 shows some of the reference trains needed to prove that a sound level meter conforms to the requirements of Australian Standard ASZ38, that is that it can be classed as a Precision Sound Level Meter.

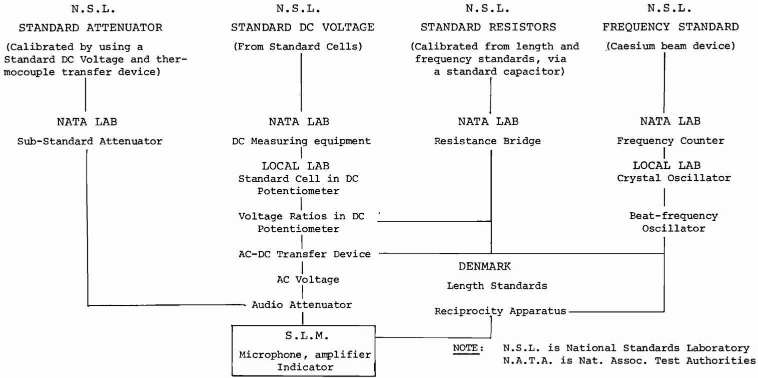
The reference trains are shown here as passing upwards from the equipment under test. The first step is to a section in the same laboratory but with higher authority in the field of measurement. The next upwar step is from this latter section to an independent laboratory of still higher authority, gained by direct checks at the National Standards Laboratory.

MEASURING TO A STANDARD OR A CODE

Most complex measurements, such as those in acoustical applications, are made according to some Standard or Code.

It is clearly important to observe the requirements of the procedure being used, and these almost always include instructions regarding the calibration of the item or items of measuring equipment concerned. It will often be found, moreover, that the same piece of measuring equipment needs calibration by different procedures, or to differing levels of precision, when applied in the variety of ways that may occur in

DIAGRAM 1



<u>NOTE</u>: N.S.L. is National Standards Laboratory
N.A.T.A. is Nat. Assoc. Test Authorities

ordinary practice. In other words, because an instrument has been "calibrated" does not necessarily mean that it can be depended upon to have the precision and accuracy demanded in all cases. This is something which must be considered every time that preparations are being made for a particular piece of work. It is not suggested, of course, that a complete calibration is needed every time an instrument is taken out of its carrying case -- simply that thought must be given to the possible need for more or less elaborate investigation of its performance.

Some judgement is ordinarily used when deciding the need for "calibration". From experience with particular instruments one comes to know how long a period may with reasonable safety be allowed between full checks of all aspects of the performance. Between these, which may well be months, or even years, apart, some brief form of test, carefully chosen, can give the assurance needed. For instance, a condenser microphone should be tested for frequency response prior to use. To do this fully is an elaborate exercise. Experience has shown, at least with one well-known make, that checking the sensitivity by using a piston-phone or other reliable reference sound source, together with visual inspection of the diaphragm, is adequate over quite long periods -- many months, perhaps, if the device is not exposed to bad field conditions. However, it is of great importance that more extensive checking be carried out at the first sign of deviation from normal performance or appearance.

AUTHORITY OF THE "AUTHORITY"

The writer has often observed a misunderstanding, by the users of measuring equipment, of the necessary qualifications of a checking or calibrating authority. It is commonplace to hear, for instance, the statement that a given instrument was "calibrated" in such and such a laboratory, so it must be in good order. At least two possiblities should be considered: firstly, whether the checking laboratory properly understood the precise requirements of the user of the instrument, that is to what Standard or Code the performance must conform, and secondly, whether the check laboratory had, in fact the competence to do the work required. (It must be stressed that the given laboratory may have been quite honestly ignorant of the real needs of the situation).

It will be noted that in the example given earlier, of a complex calibration, reference was made to a NATA (National Association of Testing Authorities) Laboratory as one of the "authorities". It has been a leading purpose of NATA to remove the risk, mentioned above, o honest ignorance of measuring and calibration requirements. (See NATA AND NOISE, by G.W. Patterson; Bulletin Vol. 2, No. 1, 1973). Whether or not any given laboratory is registered with NATA for the class of measurements it regularly carries out, the principl set down by NATA represent good practice and are worth of consideration at all times.

A final thought: Because a measuring device is new, or just repaired, is not necessarily a reason for assuming that it is correctly calibrated. On the contrary, in such cases formal testing is probably more important than at any other time.