MEASURING THE ACOUSTIC CHARACTERISTICS OF CLADDING MATERIALS

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1.0 Introduction

Considerable progress has been made recently in the development of energy-image-source theories [1,2] which predict the propogation of sound in disproportionate, non-diffuse spaces, in particular factory buildings. However, in order for these new theories to be directly usable by noise consultants and building designers, it is necessary to deteremine accurate values for the parameters in the models.

Factory sound fields are strongly affected by the internal surface absorption of the enclosure. The trend in industrial building design is towards the use of lightweight cladding panels, ranging from metal profiled sheet and composite panels to glass-reinforced cement and plastic sandwich construction panels. This trend presents the need to develop an accurate technique for measuring the absorptive properties of such panel arrays.

Of particular importance are the low frequency values and the dependence of absorption upon angle. Theorectical studies using finite plate models [3] indicate that at low frequencies the absorption of claddings is due to the dissipation energy in the vibration of the component panels on the interior surface. Finite and infinite plate absorption models [4] have indicated that arrays of regularly repeated panels have pronounced angular variation of absorption and exhibit a high absorption coefficient at angles close to grazing incidence.

2.0 Lightweight cladding panels

Due to their flexibility and interchangeability there has been a big increase in the use of architectural claddings. Previously claddings were only used on pretiguous projects, but now their use has been extended to all kinds of industrial and commercial buildings.

There is now a wide range of lightweight cladding in sheet and panel form avaliable to architects [5], enabling them to select the panel most suitable for each particular application. The characteristics of these lightweight panels are summerised in the tables shown in figures 2.0(a),(b) and (c).

2.1 Profiled Sheeting

Profiling imparts stiffness and hence strength to thin and otherwise flexible skins. Profiles are either sinusoidal with soft edges or trapezoidal where the sheets are rolled with sharper edges into troughs and ridges. Trapezoidal profiled sheets are generally preferred by architects and there is a very wide range available. The variety is illustated in figure 2.1.1. With the accessories available from manufacturers, profiled sheets can satisfy most applications.

Generally, the weighted sound reduction index is quoted as being no better than 28dB for 0.9mm profiled steel sheeting or 18dB for 1.2mm profiled aluniminium sheeting, and its value as a function of frequency can vary with profile depth. Friberg [6] found the random incidence absorption of 0.7mm profiled steel sheeting to be 0.12, and that any increase in profile depth and thickness would result in an increase in absorption, especially at resonance.

When the sound reduction is important, additional insulation should be used. With a backup of mineral wool and plasterboard, as illustrated in figure 2.1.2, it is possible to acheive up to 36dB sound insulation. Alternatively plasterboard alone or a steel liner tray with 12.5mm urethane give 32dB. Additional insulation also increases the overall absorption of the cladding and hence affects the internal sound field of the building.

2.2 Composite metal panels

The most common type of composite panels are sandwich panels. There are various types of core materials that can be used, including:-

* honeycomb (in paper and aluminium)
* mineral wool
* polyurethane (usually foamed)
* bead polystrene and extruded polystyrene (styrofoam)
* PVC

The use of any particular type or thickness of core depends upon the requirements for stiffness of the whole panel and for the thermal and acoustic performance. The simplest way of increasing the insulation performance of metal sheeting is to bond profiled aluminium or steel sheet to sheet insulation. Alternatively, panels of profiled sheeting, insulation and a lining can be made on a continuous foam-in-place production line. These methods are illustrated in figure 2.2.1.

Both the sound reduction index and absorption of composite panels will depend upon the core material used, and hence the building's internal sound field. Increasing the thickness of the core material, increases the mass and stiffness of the panels, and hence increases their absorption.

2.3 Glass reinforced polyester (GRP) and glass fibre reinforced concrete (GRC)

One main advantage with GRP and GRC is their mouldability and hence variety of possible profiles. GRP also has high strength to weight ratio. However GRP is more expensive on a volume basis than most other building materials. Sandwich or double skin construction panels are available in both GRP and GRC, although where shaped GRC panels are required, a single skin construction is recommended. According to manufacturers, a 10mm single skin of GRC at 20 kg/m^2 density gives an average sound reduction of 30 dB over the normal frequency range. Even if the skin thickness is doubled to 20mm, beyond that normally recommended, the average reduction is only 35dB. For better acoustic performance, a sandwich construction should be used. However, if preformed webs are necessary for structural reasons, the sound reduction index of the panel will reduce. To date no absorption measurements of this type of cladding has been found. It is hoped that samples can be obtained for investigation.

3.0 Practical considerations when measuring acoustic characteristics of claddings

Factory wall and roof constructions which make use of cladding can be considered to be a finite array of panel absorbers. Guy et.al. [7] reported that the acoustic behaviour of panels is effected by:

* size of test panel.
* mounting of test panel.

These factors must be considered when assessing a particular technique for the measurement of acoustic characteristics of panel absorbers.

In addition, because it has been established that the sound field in a factory is non-diffuse, we should note:

* the sound field in which the measurement is made.

3.1 Review of Methods for the measurement of acoustic absorption

An investigation has been made into several different methods for measuring the absorption characteristics of different cladding materials. These methods can be categorised as follows:

* reverberant chamber measurements.
* impedance tube measurements.
* intensity techniques.
* impulse techniques.
* phase gradient measurements.

This project group has carried out experimental measurements on profiled steel cladding using the first three techniques listed above and hopes to present some of the results at the conference.

A brief description of each of the method now follows, concentrating on the practical difficulties involved.

3.1.1 Reverberation room measurements

The random incidence absorption coefficient of a material can be measured in a reverberation room. To measure cladding materials a transmission suite is used where the source room is considered to be the reverberation chamber required for the conventional method and the recieving room is made absorbent in order to provide a free-field backing. The cladding is mounted in the aperture, using the same structural support and fixings as typifies an industrial construction. This is illustrated in figure 3.1.1. The random incident absorption of the sample is measured in the conventional manner:

$$\alpha = 0.161 \frac{V}{S} \left[\frac{1}{T_1} - \frac{1}{T_2} \right] \qquad (1)$$

Where T_1 is the reverberation time of the empty source room and T_2 is the reverberation time after the cladding sample has been mounted in the room. V is the volume of the source room and S is the surface area of the sample.

However, there are drawbacks in this method. Firstly, the measurement is made in a diffuse sound field, whereas the prediction models are for non-diffuse spaces. Secondly, the method only gives the random incidence sound absorption, so the angular dependence can not be determined. Also, the size of the sample is limited, and the boundary conditions, which strongly determine the acoustic characteristics of panel absorbers (especially at low frequencies) are not truly represented. Investigation is being made into the effect of different mountings, although this is limited to the design structure specified by the manufacturer.

3.1.2 Impedance tube techniques

Three different types of impedence tube methods are being investigated:

* standing wave ratio; standard impedance tube method
* wave-tube tone burst; Vigran method [8]
* wave-tube impulse; Ding Yong-Sheng method [9]

The impedance can only be measured at normal incidence and at low frequencies. Due to the occurence of cross modes a high frequency limit exists on impedence tube methods . However, techniques have been suggested that extend the measurement range by 2 or 3 octaves. For instance, Vigran proposed that the impedance tube be subdivided into a group of smaller parallel ducts. This technique is to be investigated further. Ding Yong-sheug's method using impulses is illustrated in figure 3.1.2. The same principle is applied as described in section 3.1.A. to find the reflection coefficent of the test material. Comparisons between this method and the standing wave tube method showed that data measured by the latter began to distribute randomly above 700 Hz, making it difficult to measure low values of reflection coefficient. Measurements from the wave tube impulse method clearly indicated the low values. With a complex FFT transform procedure the complex impedence could also be found with the same precision.

The impedence tube has the advantage that it is a quick and convienient method for comparative measurements. However, if very small samples are used, the results are thought not to represent the whole surface of the cladding and can only be taken as an indication of the relative absorption of the test samples. Both the tone-burst and impulse methods overcome the single frequency limitations of the standing wave ratio method, but difficulties have been encountered due to excitation of higher vibration modes in the tube.

Referring back to the practical consideration of measuring the acoustic characteristics of factory claddings, the main drawbacks of the impedance tube methods are the small size of the test sample and its mounting in the tube. As previously mentioned, the panel action of claddings and the size and mounting of a sample will have a critical effect on its behaviour, particularly in the low frequency range of the impedence tube method.

This research group is experimenting with this method using a 6m tube with a sample of 70 x 70 cm mounted in the tube such that its behaviour would be as part of an infinite sample, eg. like a speaker cone. Mountings, eg. neoprine, are being considered into which the vibration of the cladding sample propagates such that it would be quickly attenuated but not reflected, hence simulating the behaviour of a wave in an infinite sample.

3.1.3 Intensity techniques

Several papers have been published recently describing methods for measuring the acoustic characteristics of materials using the intensity method [10].

In the laboratory, the sample can be mounted in a reverberation room, adjacent to a semi-anechoic space in the same way as described above. The experimental setup is illustrated in figure 3.1.3. The incident sound intensity can be calculated from the reverberant sound pressure level,

$$IL_i = SPL_i - 6 \quad dB \qquad (2)$$

The absorbed intensity in proximity to the material is determined by scanning the sample with the intensity probe,

$$IL_a = IL_i - IL_r \quad W/m^2 \tag{3}$$

The random incidence absorption factor is calculated from

$$\alpha = \frac{I_a}{I_i} \tag{4}$$

hence,

$$10 \log \alpha = IL_a - SPL_i + 6 \quad dB \tag{5}$$

One obvious advantage of this method over the conventional room method is that the sample remains in place for the whole measurement procedure. Measurements are being made using this method, using both a B&K intensity probe with dual channel signal analyser type 2032, and a Nortronics 216 intensity probe and real time analyser type 830. Also, the following experimental details are being investigated:

* distance of probe from cladding sample - should it vary with profile?
* angle of probe in relation to profile of cladding.
* angle of probe in relation to plane of cladding.

Under laboratory conditions the same limitations apply as for the conventional method. However, the intensity method can be used in-situ.

3.1.4 Impulse techniques

An impulse measurement technique to determine the absorption of factory roofs was described by Orlowski [11] as follows. A short sound pulse $R_1(t)$, the half-cycle of a sine wave at an equivalent frequency of 200Hz, is radiated from a highly directional 3.3m column speaker. The resultant impulse response $R_m(t)$ is then recorded with a microphone at various distances from the source, corresponding to different angles of sound incidence with the roof. The recorded signal is electronically gated to isolate the reflection from the roof. The ratio of the reflected and direct components (the latter having been corrected to correspond to the distance travelled by the reflected pulse assuming spherical divergence from the loudspeaker) gives the reflection coefficient, and hence the absorption coefficient at a particular angle of incidence.

$$\alpha(f) = 1 - \frac{R_m(f)}{R_1(f)} \tag{6}$$

Difficulties with this method are isolation of the direct and reflected impulses and choice of sampling time of the reflected impulse. The former is overcome by using a shorter impulse. However, the latter presents a problem with panel absorbers (such as cladding), because panel resonances are excited. These may result in a longer reflected impulse than the incident impulse, and the decaying reflected impulse may become indistiguishable from electric noise in the electronic detection circuitry. In addition, it is has been found difficult to achieve high accuracy for low absorption values and the apparatus has practical limitations. However, this technique provides an in-situ method for measuring absorption as a function of angle.

3.1.5 Phase gradient measurements

A phase gradient method desribed by Leguis and Nicolas [13] to measure the normal specific impedence of porous materials at low frequencies, involves measuring the phase gradient as a function of distance normal to the material and passing through the source, using a dual microphone probe. The method requires a minimum of instrumentation, provided its precision is sufficient to measure small phase differences between the microphones. Low frequency ground impedence measurements down to 30 Hz have been reported.

Daigle and Strinson [13] describes a similar technique, stressing the effects of extraneous reflections, and the importance of making the measurements in the absense of reflections. This may limit the use of the technique for cladding materials, but this method is being investigated further.

4.0 Summary

With the advent of greater variety of cladding materials being used in the construction of commercial and industrial buildings, there is a need for methods to measure their acoustic properties for the use by architects and building designers.

In order to predict the internal sound field of disproportionate buildings, the absorption coefficient of its constructional materials and information as to the variation of absorption with angle of incidence are required. The different techniques for measuring the absorption of claddings are summerised in table in figure 4.0. It is hoped that eventually one method will emerge as giving values of sufficient accuracy for use in the new prediction methods being developed.

5.0 Acknowledgements

This work which forms part of a project concerned with predicting noise levels in factory building is supported by a grant from the Science and Engineering Research Council and supervised by Dr R.J. Orlowski.

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TABLE 1a. Summary of characteristics of lightweight sheet and composite panel claddings

	Steel Profiled Sheet	Aluminium Profiled Sheet	Fibre Cement	PVC	GRP	GRC
Texture	Grained or smooth		Self textured	Smooth	Textured or smooth	
Colour	Large range including brighter colours		Limited range, generally dark colours	Normally translucent	Medium range of colour pigments	Cement colour
Profiles	Rounded or sharp		Rounded	Rounded	Large variety of profiles possible	Shaped panels are recommended in single skin construction
Finish	Needs applied finish to resist corrosion	Applied finish not necessary (but coating usually applied to increase durability and reduce glare)	Natural finish	No finish necessary	Pigmented resins.Gel coat resins protect glass fibre reinforce-ment	Natural finish, or applied permeable finishes used to allow GRC to breathe
Strength and stability	Good tensile strength & impact resistance	Greater acceptable deflection than asbestos or steel. Less resistant to soft impact than steel	Bending strength varies with profile. Impact strength reduces with age	Less tolerant of deflection than metal sheeting	High tensile strength but low modulus of elasticity. Panels need stiffening	Tensile & impact strength reduce with age

FIGURE 2.0(a)

TABLE 1b. Summary of characteristics of lightweight sheet and composite panel claddings (cont'd)

	Steel Profiled Sheet	Aluminium Profiled Sheet	Fibre Cement	PVC	GRP	GRC
Size	Preferred max length 13 m depending on profile.Max width 1 m		Max length 3.05 m.Max width 1.2 m	Max length 10 m.Max width 1 m	Max length 4-6 m.Max width 2 m	
Compar-ability	No reaction	Needs to be isolated from some building materials,eg,steel cladding rails and cement	No reaction with cement concrete or plaster(but check about aluminium	Compatible with metal profiled sheeting	No reaction with other materials (but glass fibre needs protection)	Check with manufact-urers on compatib-ility with aluminium
Composite claddings	Generally only available faced with profiled steel or aluminium			Sealed units & twinwalled system	Double skin/sandwich construction panels available in both GRP and GRC	
Types of insulation core	Polystyrene, polyurethane honeycomb, mineral wool cores		Insitu only		Polystyrene rigid sheet or poly-styrene foam	Polystyrene or polyurethane
Fire	No fire resistance without fire-resistant lining		Non-combustible	No fire resistance	Fire-retardent additives required	Non-combustible

FIGURE 2.0(b)

TABLE 1c. Summary of characteristics of lightweight sheet and composite panel claddings (cont'd)

	Steel Profiled Sheet	Aluminium Profiled Sheet	Fibre Cement	PVC	GRP	GRC
Acoustic characteristics	Maximum SRI of steel profiled sheets is 28dB, less for aluminium. Maximum SRI of composite panels is 41dB. Increase in profile height gives a small increase in SRI. Increase in profile depth gives increase in absorption especially at resonance. Absorption of profiled sheets is better at low frequencies than of flat sheets.				Single skin GRC gives an average SRI of 30dB. Sandwich panels give greater acoustic performance	
Costs	Fibre cement tends to be cheaper than aluminium. Finishes and supporting structure will effect cost. Composite panels (depending on profile) are more expensive.			GRP most expensive material, but lightweight panels reduce the cost of the supporting structures.		

FIGURE 2.0(c)

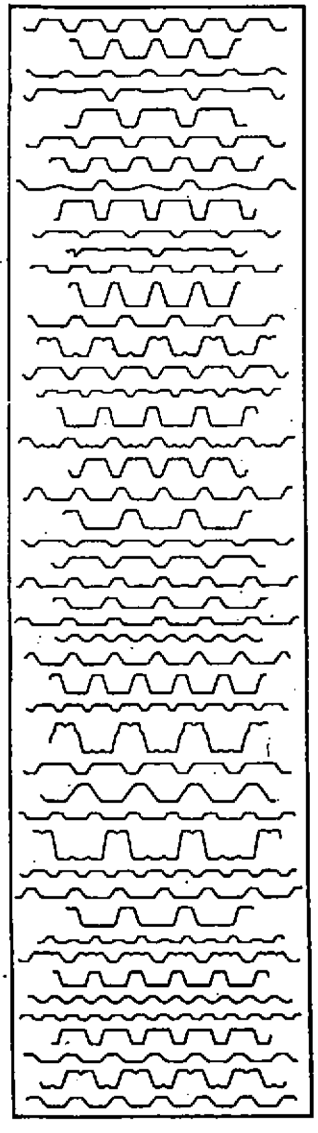

Figure 2.1.1 Variety of cladding profiles.

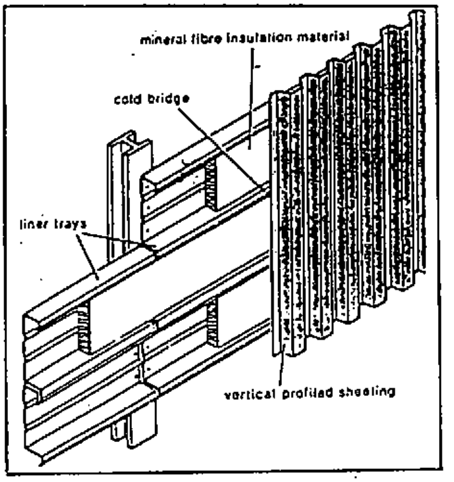

Figure 2.1.2 Liner trays in steel or aluminium support insulation in cavity.

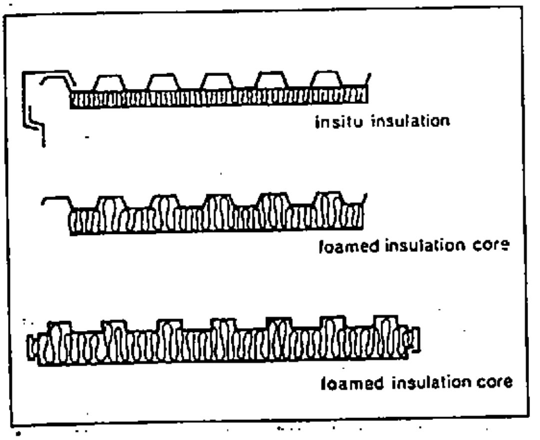

Figure 2.2.1 Alternate methods of insulating profiled cladding.

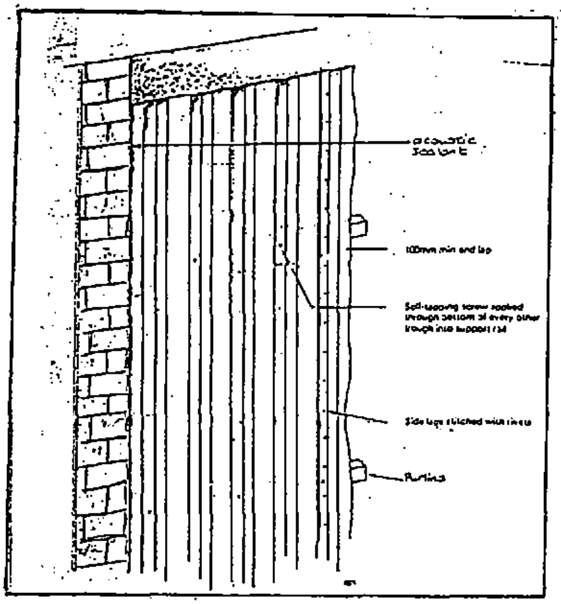

Figure 3.1.1 Mounting of cladding sample in transmission suite.

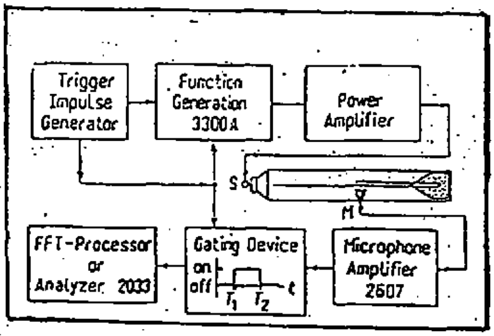

Figure 3.1.2 Block diagram of apparatus used in the wavetube impulse method, as used by Ding Yong-Sheng.

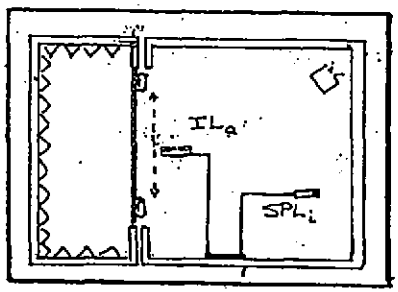

Figure 3.1.3 Measurement of absorption coefficient using intensity probe.

TABLE 2. Summary of methods for measuring the absorption co-efficient of claddings for the prediction of sound propagation in factories.

	Frequency Range (Hz)	Advantages	Disadvantages
Reverberation Room	100 - 8K	. Recognised standard method. . Easy to perform.	. Large facilities needed and boundary conditions limited. . Diffuse sound field. . Random incidence only.
Impedance Tube	50 - 500	. Quick comparative method. . Mounting restrictions could be overcome.	. Small size of sample. . Normal incidence only.
Intensity Probe	125 - 5K	. Measurements can be made insitu. . Potential for providing very simple method of measurement. . Potential for providing angular information, but risk of specular reflection.	. Technique still under investigation.
Impulse Method	63 - 8K	. Provides angular information. . Measurement can be made insitu.	. Difficult to achieve high accuracy at low absorption. . limitations to practicability of apparatus.
Phase gradient method	30 - 1K		. Normal incidence only. . Cannot be measured insitu. . Effects of reflections.

FIGURE 4.0

THE USE OF CEPSTRAL ANALYSIS FOR PITCH CONTOURS IN SPEECH

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INTRODUCTION

Fundamental pitch (T_x), is a basic parameter of a speech signal and is present only in voiced segments. Voiced sounds are produced by the periodic vibration of the vocal folds, filtered by the vocal tract. Unvoiced speech is produced by turbulent bursts of air, which appears as shaped white noise.

The pitch extractor should in the first instance be capable of making the voiced-voiceless distinction. This can be particularly difficult where voicing is weak, or where frication masks voicing; for example in voiced fricatives.

It is desirable to produce a pitch extractor that is able to obtain the pitch information of a voiced speech signal quickly and efficiently, with voiced-unvoiced discrimination.

Bogert described the principles of cepstral analysis in 1959, and used it for investigation of echoes in seismic signals. Tukey and Bogert [1] published the findings of their research; but it was Noll [2, 3], who first put forward the application of short term cepstra for fundamental pitch extraction. His cepstrum pitch detection algorithm was the first short term analysis that proved realisable by computer.

THEORY

The voiced speech signal can be considered to be built up of two components; (i) the periodicity due to the glottal pulse train, and (ii) the vocal tract transfer function. It is possible to treat these processes as linear and independent. The output speech signal is the convolution of (i) and (ii). The power spectrum of a voiced speech segment exhibits a low frequency periodicity due to the vocal tract, and a high frequency periodicity due to the vocal source. (This gives the effect of a high frequency ripple superimposed upon a low frequency variation.)

Taking the Fourier Transform of the logarithm of the power spectrum separates the vocal tract and vocal source effects. The cepstrum will show low 'quefrency' values due to the vocal tract, and a high 'quefrency' value due to the vocal source. This high quefrency peak corresponds to the fundamental pitch, T_x.

If x(n) represents the output speech signal from the lips, p(n) the transfer function of the vocal tract, and s(n) the glottal pulse train from the vocal source, then:

$$x(n) = p(n)*s(n) \quad (1)$$

This is the convolution of the two respective functions in the time domain. The Cepstral analysis technique separates the two functions as follows:

Taking the Fourier transform of (1) gives:

$$X(\omega) = P(\omega).\ S(\omega) \quad (2)$$

where $X(\omega)$, $P(\omega)$ and $S(\omega)$, are the fourier transforms of $x(n)$, $p(n)$ and $s(n)$ respectively.

Taking modulus and squaring equation (2).

$$|X(\omega)|^2 = |P(\omega)|^2 + |S(\omega)|^2 \quad (3)$$

Taking logarithms converts this product to a sum:

$$\text{Log } |X(\omega)|^2 = \text{Log } |P(\omega)|^2 + \text{Log } |S(\omega)|^2 \quad (4)$$

This is the logarithmic power spectrum. Now, taking the Fourier Transform of (4) gives the spectrum of the power spectrum which is defined as the Cepstrum

$$C(\tau) = \text{F.T.}(\text{Log } |X(\omega)|^2) \quad (5)$$

Normally $10\text{Log } (C(\tau))$ is plotted against quefrency.

PROCESSING SPEECH

As speech is continually changing, it needs to be processed in sample segments that are large enough to yield useful information about their pitch, but not so large that the pitch changes appreciably within a segment; as this will cause wider, less precise peaks. Also the Fast Fourier Transform algorithm used, (a radix-2 method [7]), requires the number of samples to be an integer power of 2. The chosen segment size was 512, corresponding to 51.2 milliseconds, for a sample rate of 10kHz. This gives an acceptable compromise between resolution, accuracy and speed.

The required segmentation is achieved by multiplying the time signal by a Hamming window of length 512. This also limits the amount of spectrum leakage.

The Cepstrum algorithm used in fig 1 is based upon Noll 1967 [3]. Removing d.c. bias before the FFT is necessary to prevent a large peak occurring at zero on the spectrum and cepstrum; which can overshadow the remaining information.

The spectrum can be processed to ensure that the formant effects do not distort the cepstrum in the vicinity of the voicing spike. The three most useful methods for this are Inverse Filtering [7], Spectrum Flattening [7], and Centre-Clipping [9].

The fundamental frequency for an average male speaker is 60-400Hz [5]. The cepstrum is therefore 'liftered' between quefrencies of 2.5 and 15ms; which removes the quefrency vocal tract formants.

A peak picking algorithm is implemented, with a check for pitch doubling which relies on a past knowledge of pitch values.

The window is shifted by 20ms (approx 50% overlap) between cepstra, and a voiced-unvoiced decision made. This is based upon zero-crossing [6] and relies on unvoiced speech being similar to white noise; which has a large number of zero-crossings compared with voiced speech. An alternative method of voicing decision is that of considering the power within a speech segment [5]. The power in an unvoiced speech segment is much less than that within a voiced speech sample. An energy threshold can thus be set, and the voicing determined. (In both these methods the threshold can be altered to allow weakly voiced speech segments to be analysed.)

Once the whole speech sample has been scanned, a pitch contour can be plotted of fundamental frequency vs time. Any invoiced segments will be zeroed.

The program which has been developed was tested using a synthetic test signal [10] of the phoneme /i/; which had a gradually increasing pitch. The results of this test are shown in fig 2.

CONCLUSIONS

The cepstral analysis technique is an effective method of fundamental pitch extraction. It provides an accurate estimation for the pitch period of a voiced speech segment, and enables a pitch contour to be obtained.

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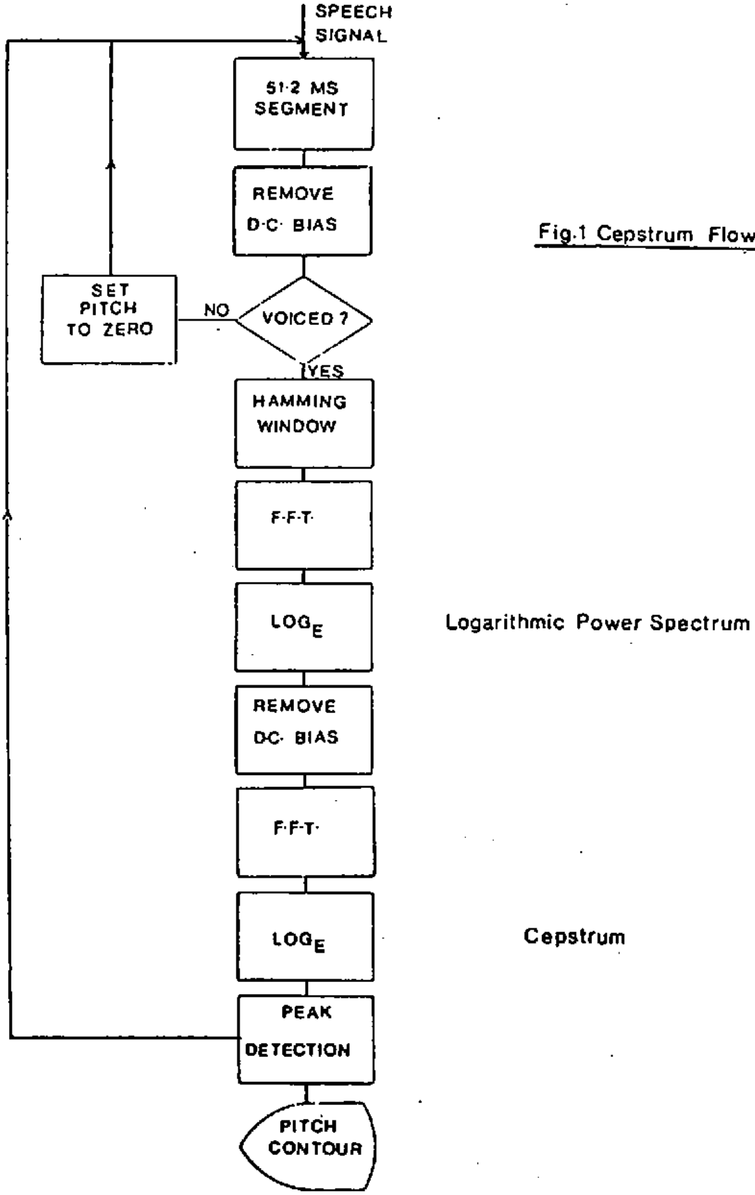

Fig.1 Cepstrum Flowchart

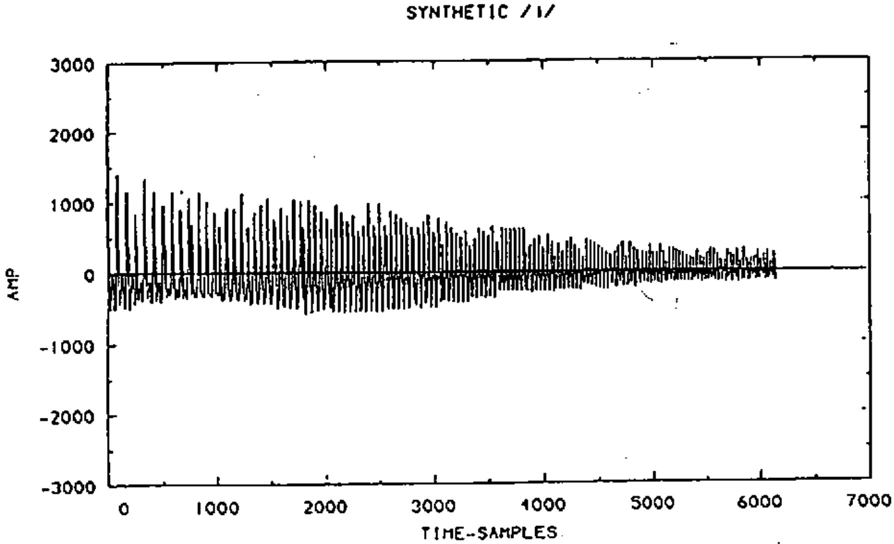
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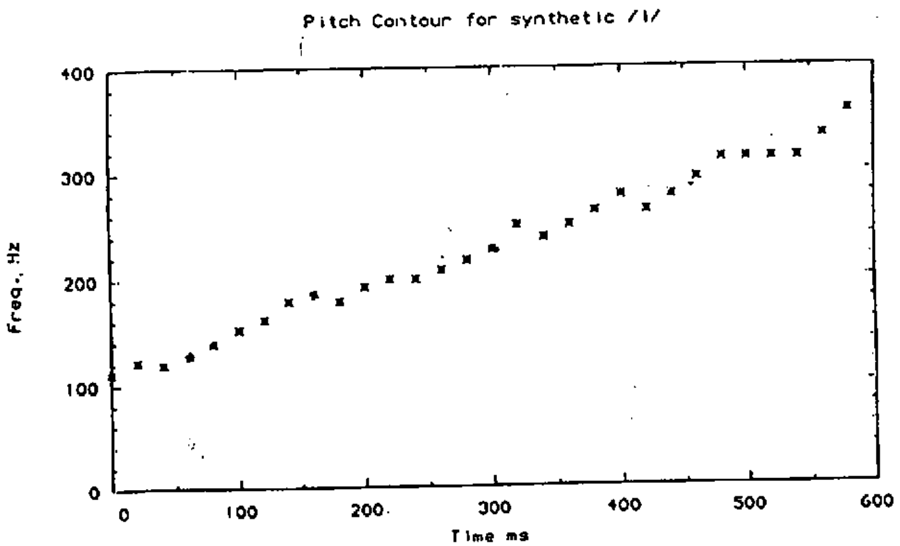
Fig. 2


Pitch Contour for synthetic /I/
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300
200
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