Proceedings of the Institute of Acoustics

APPLICATION OF ELECTRONIC AMPLITUDE SENSITIVE EAR MUFFS IN RIFLE RANGES

Darran Humpheson and Ralph J. Weston

RAF IHMT, RAF Halton.

1. INTRODUCTION

The introduction of the peak action level [1] has done much to focus the attention of the level of hearing protection afforded to users of firearms, whether for 'sporting use' or for firearm training. This increased awareness has led to a growth in the number of passive and active hearing protectors which are on the market. The choice is some what daunting and is dependant on their application and the minimum attenuation which they offer when subjected to impulse noise above the 200 Pascal (140dB SPL) peak action level.

In many instances the user wants to communicate freely and yet, at the same time, be assured that he his fully protected from high levels of unwanted sound.

The techniques of controlling high impulse noises whilst allowing speech through are well known. This paper describes the application of Electronic Amplitude Sensitive Ear Muffs (EASEMS) for use in military rifle ranges. The selection of this form of hearing protection is outlined along with a brief discussion on the performance and testing of active non-linear devices.

2. REQUIREMENTS FOR HEARING PROTECTION IN RIFLE RANGES

Military rifle ranges are on average 25 metres long and the firing points can be either open or enclosed, to offer protection from the weather. The ranges main purpose is to provide light weapon experience, in the form of pistols and rifles, to military personnel undergoing initial and annual weapon training. The impulse noise generated by these weapons exhibit the classical Friedlander waveform, shown in Figure 1, with very short rise times, typically 30μs and durations of approximately 300μs. The bandwidth of the resulting spectra is very large and peak levels in the range 145 to 168dB [2] can be expected.

Figure 1 - Friedlander Waveform

As stated previously, the main use of rifle ranges are for the instruction of personnel on the correct procedure for weapon firing. A factor, which arises from the wearing of passive protection, is the resulting loss of speech intelligibility between the weapon firers and the range controller. Experience has shown that instructions can be easily misunderstood. This can lead to serious consequential safety hazards. In the past this has led to the protector either being lifted off the ear or not being worn at all. Breakdown in communication is sometimes compounded by the poor design of the rifle range which leads to a very reverberant firing enclosure.

Considering the aforementioned characteristics of the impulsive noise experienced in rifle ranges, the issued hearing protector must satisfy the following criteria:

2.1 Minimum attenuation

The weapon type will dictate to a degree the peak level and frequency spectra received at the firer's ear and also to other personnel on the rifle range. The position of the firer relative to the weapon and also any reverberation affects within the firing enclosure will also vary the characteristics of the sound. An interesting occurrence in rifle ranges is the repeated and sometimes apparent constant firing of the weapons. The cumulative effect [3] of this multiple-shot exposure can eventually lead to the first and second action levels being exceeded for ranges where approximately 3000 rounds of ammunition are used per day. In practice the number of shots fired on a range is unlikely to exceed 2000 rounds.

To provide adequate protection a mean attenuation of at least 28dB is required.

2.2 Safe Communication

The hearing protector should provide amplification of the wanted sound to a safe level. That is, the ear must not be exposed to levels in excess of a $L_{EP,d}$ of 85dB(A) (military standard). The device must be able to react fast enough to provide full passive protection.

3. APPLICATION OF EASEMS

EASEMS incorporate either one or two microphone(s) on the outside of the muff and small loud speakers inside the muff. At low ambient noise levels the external sound is transmitted electronically and above a certain level, either of two electronic circuits can be used to reduce the high noise levels:

a) A peak limiting circuit restricts the damaging high level sounds/signals being transmitted to the earphones and the inherent attenuation of the muff then provides the protection.

b) A control loop circuit uses a compressor to progressively reduce the amplitude of high noises, up to a level when the muff then provides the required attenuation.

These protectors are either provided with one microphone and amplifier configuration, or a twin system for providing localisation of the sound source. The attenuation of these devices vary but typical levels of 25-28dB are obtainable for impulsive noise measurements.

3.1 Selection

When we came to select a suitable EASEM, it was found that there was little or no data available for the products on the market, not even a passive attenuation rating and independent tests had to be commissioned.

The most noticeable quality about EASEMS is their ability to protect against high level impulsive noise, while allowing communication during low ambient sound levels. Accordingly, when used in rifle ranges the trainees can easily recognise instructions and warnings.

The majority of EASEMS provide a gain control for the adjustment of the volume of the transmitted ambient noise. Tests have shown that in certain combinations of gain settings coupled with the external sound levels, the levels received at the ear can be above the external level. In extreme cases the levels received at the ear were found to be above the first and second action levels.

Certain protectors trade their cut-off performance against the passive attenuation which they offer to the wearer. Protectors where the electronic circuitry is incorporated into the muffs lead to a reduction of the passive attenuation compared with conventional hearing protectors. Being heavier than passive hearing protectors and also containing electronic circuitry they are more susceptible to damage and can be uncomfortable when worn for long periods. Finally, they are very expensive.

4. PERFORMANCE AND TESTING OF EASEMS

Currently there are no British, International or European Standards to aid users in the selection and use of these type of devices.

4.1 Steady State Performance

Steady state performance has been tested by Wheeler [4] and can be tested in accordance with the latest series of European Standards for passive hearing protectors. In addition a new test needs to be developed to check that with the amplification set to maximum, the addition of external sounds with the amplified sound does not exceed a set level at the ear.

4.2 Dynamic Performance

Dynamic performance was evaluated by Wheeler [5], the method he used involved the "microphone in the concha" technique in a anechoic chamber. A starting pistol was used to provide a clean impulse in the 160-165dB SPL peak range. Internal and external sound levels were recorded and the impulse attenuation data was presented in three metrics: linear peak (20Hz - 20kHz bandwidth), C-weighted peak and A-weighted SEL.

The results correlated well with the steady state performance measurements, but still leave a number of performance aspects untested. The principal aspect is the very wide bandwidth of light weapon impulse spectra and the non-linearity of passive protectors. Secondly, the ability to cope with the 30μs rise time of the impulse signal is an important factor in the performance of the EASEM to fully protect the wearer. In our situation, where reverberant and repetitive conditions exist, a desirable feature of the EASEM would be a delayed restoration of the ambient working conditions.

4. CONCLUSIONS

With an increased awareness for the need for adequate hearing protection on military rifle ranges their has been an increase in the number of enquiries for the issuing of EASEMs. Their ability to provide adequate hearing protection whilst allowing communication at low ambient levels is vital for range work. However, an International Standard for their performance under steady state and impulsive conditions needs to be created in order to safeguard the user.

5. REFERENCES

[1] HEALTH AND SAFETY EXECUTIVE. "Noise at Work Regulations 1989". HMSO, London. 1989.

[2] D. HUMPHESON. "A report on a noise survey of the 25m range at RAF Locking." Report No: 29/93. RAF IHMT. 1993.

[3] G PARKER. "A review of hearing protection for firearms training" Publication No:12/91. Police Scientific Development Branch. 1992.

[4] P.D. WHEELER. "Steady state performance measurements for Electronic Amplitude Sensitive Ear Muffs (EASEMS)". Ref N757. Salford University Business Services Ltd, Industrial Acoustics Division. 1989.

[5] P.D. WHEELER. "Dynamic performance for Electronic Amplitude Sensitive Ear Muffs (EASEMS)". Ref N758. Salford University Business Services Ltd, Industrial Acoustics Division. 1989.

THE USE OF LOW DENSITY POLYMER FOAMS AS RESILIENT LAYERS IN FLOORS

Robin K Mackenzie, Robin Hall

Sheffield Hallam University, School of Construction, Pond Street, Sheffield S1 1WB

1. INTRODUCTION

Recent developments in the manufacturing techniques associated with flexible cellular foams have opened up new possibilities in the design of products incorporating these new materials. Research at Sheffield Hallam University during the past twenty years by Hilyard et al (1) has helped to characterise the mechanical properties of cellular foams. New research is being carried out to facilitate the evaluation of the dynamic properties of cellular foams both independently and as part of complete flooring systems. Reference is made to the use of low density cellular foam in the manufacture of resilient flooring products with particular reference to laminated and co-planar applications of open and closed cell foams.

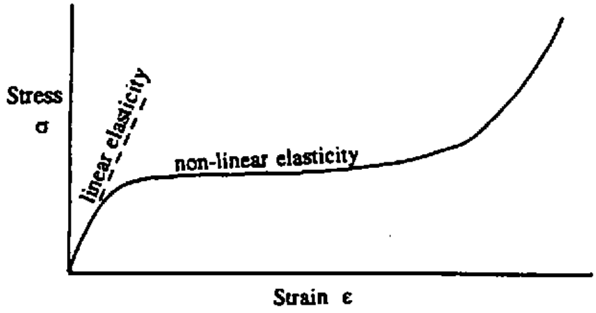
2. BACKGROUND

Current standard test procedures (2) for the evaluation and characterisation of cellular foams used as resilient layers in buildings are limited in their scope and do not apply to complete floor systems. Most standard tests on cellular elastomer foams relate to their use as packaging or cushioning material in vehicles or furniture. A review of current testing procedures for elastomer foams is currently underway in order to establish their usefulness in predicting the dynamic performance of resilient floors. As part of this research foams are being categorised using mechanical methods developed at SHU in earlier investigations (3).

Gibson and Ashby (4) treat cellular solids as class of material with elastomer foams being just one particular form. They have modelled the behaviour of such foams by considering each individual cell in the foam to be made up of interconnected beams. Equations describing the behaviour of beams coupled with scaling laws have then been used to describe the behaviour of the bulk foam. Consideration of this approach led to the recognition that current research in the Department of Applied Physics at SHU into osteoporosis might well be relevant to this study. The commonality is that cancellous bone, like foam, is a form of cellular material and any technique which can classify bone might well be used to classify cellular foam indeed any form of cellular material encountered in buildings. Recent work undertaken now suggests that this is indeed a possibility.

Deformation mechanisms in foams

When compressed, elastomer foams usually exhibit the stress / strain relationship illustrated in fig.1.



Initially ,at low strain, linear elasticity (cell wall bending) followed by a "plateau" (elastic buckling of cell walls) where strain increases rapidly for small increases in strain and finally a steep rise in stress with strain as the matrix polymer is itself compressed following collapse of cells in the foam. Foams can be of open or closed cell form and the use of both is described in flooring systems later in this document.

Gibson and Ashby (4) propose that cell wall bending and buckling are of fundamental importance in describing the behaviour of foams and this is supported by the observations of the authors. Their characterisation of the mechanical behaviour of isotropic elastomer foams is briefly described below.

Linear elasticity

Two moduli are needed to describe linear behaviour in isotropic foams (more if the foam is anisotropic). Of primary importance are Young's Modulus (E^*), Shear Modulus (G^*) and Poisson's ratio (v^*). The moduli are expressed in terms of cell wall (base polymer) modulus (E_s) and the foam's relative density (ρ^*/ρ_s).
(N.B. the superscript "*" refers to the foam and the subscript "s" refers to the base polymer).

Open cell foam

Figure 2 illustrates cell wall bending for an open cell foam.

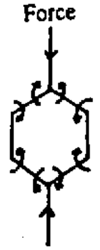
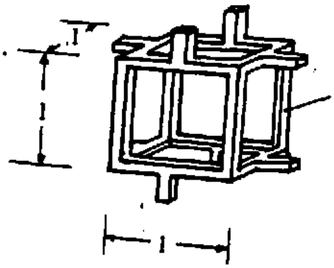


Figure 3 shows the cell model used to estimate the moduli. This is similar to the approach of Gent and Thomas (4) but here each cell is joined to another by a strut in the middle of one of its beams.



Relative density of the cell (ρ^*/ρ_s) and second moment of area (I) are related by:

$$\frac{\rho^*}{\rho_s} \propto \left(\frac{t}{l}\right)^2 \qquad (1)$$

and

$$I \propto t^4 \qquad (2)$$

For a beam of length (l) and thickness (t) loaded at its mid. point. Timoshenko (6) gives the deflection (δ) as:

$$\delta \propto \left(\frac{Fl^3}{E_s I}\right) \qquad (3)$$

and

$$F \propto \sigma l^2$$

$$\varepsilon \propto \frac{\delta}{l}$$

Hence Young's Modulus for the foam becomes:

$$E^* = \frac{\sigma}{\varepsilon} = (\text{constant})\left(\frac{E_s I}{l^4}\right) \qquad (4)$$

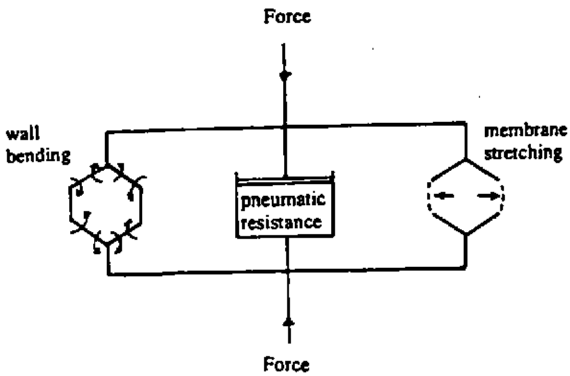
and from (1) & (2):

$$\frac{E^*}{E_s} = C_1\left(\frac{\rho^*}{\rho_s}\right)^2 \qquad (5)$$

C_1 contains all the constants of proportionality.

Closed cell foams

Closed cell foams are more complicated than open cell foams. The effects of material in the faces and fluid contained in the cell must be considered as well as the contribution of the cell edges. The situation is illustrated below in Figure 4.



Non-linear elastic behaviour

With elastomer foams, the initial linear rise of stress with strain is followed by non-linear elastic deformation. Elastic because the strain is recoverable. In open cell foams there is a long plateau as strain increases rapidly with little or no increase in stress. With closed cell foams there is an increase of stress with strain caused by gas enclosed in the cells and the cell walls themselves.

Open cell foams

The non-linear deformation of these foams is controlled by the elastic buckling of the cell edges. Buckling takes place at stress = σ_{el} illustrated in figure 1.

Euler's formula gives the critical buckling load as:

$$F_{crit} = \frac{n^2 \pi^2 E_s I}{l^2} \qquad (6)$$

As before:
l = beam length; E_s = Young's modulus; I = 2nd moment of area. n^2 describes the degree of constraint at the ends of columns. The stress (σ^*_{el}) at which buckling occurs is obtained from:

$$\sigma^*_{el} \propto \frac{F_{crit}}{l^2} \propto \frac{E_s I}{l^4} \qquad (7)$$

From equations 1 & 2:

$$\frac{\sigma^*_{el}}{E_s} = C_2\left(\frac{\rho^*}{\rho_s}\right)^2 \qquad (8)$$

C_2 contains all the constants of proportionality.

Closed cell foams

With closed cell foams elastic buckling is modified by the gas contained in the cells and probably by the cell faces as they fold over themselves. As cell walls buckle then the pressure of the gas can be expected to increase which suggests an explanation of post buckling behaviour. These foams exhibit an increase in the gradient of stress / strain graphs.
Critical buckling stress is given by:

$$\frac{\sigma^*_{el}}{E_s} = (\text{constant})\left(\frac{\rho^*}{\rho_s}\right)^2 + \frac{p_0 - p_{at}}{E_s} \qquad (9)$$

where p_0 and p_{at} are original and atmospheric pressure respectively.
The constant has been shown to be approximately 0.05.

For manufactured foams $p_0 = p_{at}$ so enclosed gas in cells does not affect the onset of buckling but as compression increases p_0 is modified to p' where:

$$p' \approx \frac{p_0 \varepsilon}{1 - \varepsilon - \left(\frac{\rho^*}{\rho_s}\right)} \qquad (10)$$

The post collapse stress / strain behaviour is therefore described by:

$$\frac{\sigma^*}{E_s} = 0.05\left(\frac{\rho^*}{\rho_s}\right)^2 + \frac{p_0 \varepsilon}{E_s\left(1 - \varepsilon - \left\{\frac{\rho^*}{\rho_s}\right\}\right)} \qquad (11)$$

It has been demonstrated (4) that by removing the second term on the right hand side of equation 11, the stress / strain curves of closed cell foams give a curve which matches the behaviour of open cell foams.

Densification

Equation 11 fits experimental data less and less as foam density increases. Also as compressive strain increases, a point is reached where the cell walls are jammed together following near total cell collapse. It has been shown (3) that this takes place when:

$$\varepsilon_D = 1 - 1.4\left(\frac{\rho^*}{\rho_s}\right) \qquad (12)$$

Following densification the stress - strain curve rises with a gradient tending to E_s.

3. RESILIENT LAYERS FOR BUILDING USE

The advantages of open cell polymer foams for use as resilient layers has already been described in earlier publications (7-12). The characteristic difference between closed cell and open cell foam under an applied load is found in their relative static deflections. A closed cell foam strip, 12mm thick, under normal domestic loading, is unlikely to deflect by more than 1mm compared to a figure of 6mm obtained with open cell foam of similar thickness.

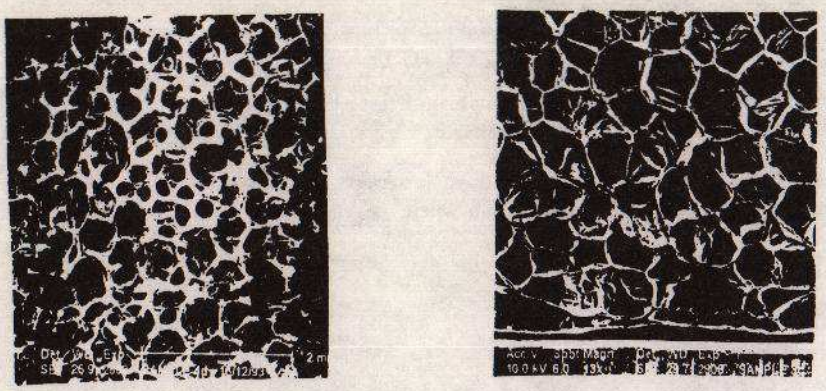


Figure 5 - Micrographs showing the different cellular structure of open cell (left) and closed cell (right) polymer foam.

Closer examination of the movement of open cell flexible foams under dynamic loading has indicated that it is the cellular structure which dictates the rate of deflection whereas it is the polymer material itself which determines its resilience or ability to return to its original state.

The main problem with rock (i.e. mineral wool) or glass fibre quilts is that they comprise of strands of brittle material (i.e. glass state) which achieve resilience by means of interweaving in free form or by resin bonding. Over a period of time these fibres break and in low density foam are frequently ground to dust.

Open cell polymer flexible foams do not exhibit such brittle fracture because of the elastic behaviour of the soft co-polymer. The only problem which can arise, therefore, is due to a breakdown in the chemical bond or a change of chemical state. Under normal domestic loading, bond breakdown is extremely unlikely and virtually impossible where cross-linking has been carried out. A change of state is, however, a possibility, with some materials more susceptible than others. Natural rubber will oxidise and after a period of time lose its resilience. This, however, is a slow process in an underfloor location where catalysts such as UV light are absent. The polyester-urethane co-polymer is essentially unstable and through being hydrolytic will, in a damp or humid environment, gradually lose its compressive strength giving rise to creep. In terms of dynamic behaviour, chemical stability and cost, polyether based polyurethane open cell foam is the most suitable material.

Applications in Floating Floors

Laminations of open-cell and closed-cell foam strips have been utilised in the design of resilient timber battens or strips.(13,14) The micrograph below shows the compression under normal domestic loading of a 10mm open cell strip laminated to a 10mm closed cell strip.

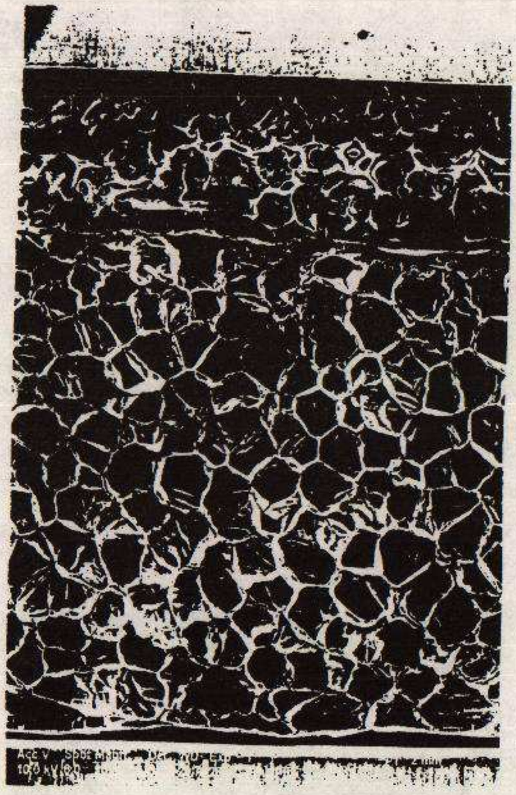


Figure 6 - Compression of the Profloor Dynamic Strip under normal domestic loading. Courtesy: Proctor Group

The 12mm thick open cell foam deflects by up to 6mm under normal domestic loading to provide a suitable isolation efficiency against impact sound. Further deflection is resisted by a combination of the elastomer in the open cell foam together with the pneumatic resistance provided by the entrapped air within the closed cell strip. The elastic behaviour under normal domestic loading, <4kPa, is clearly shown in the plateau in Figure 7, between 2mm and 6mm deflection.

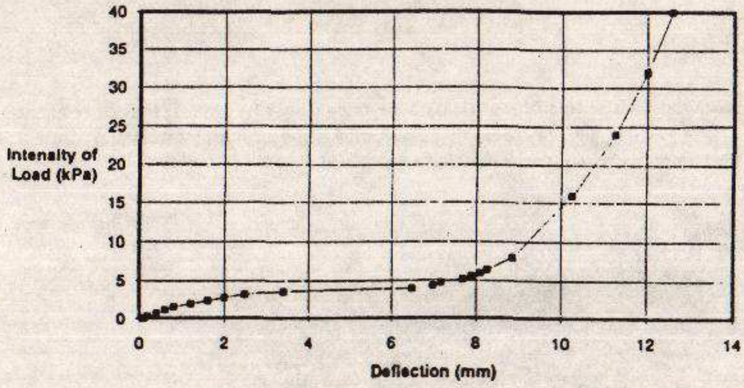


Figure 7 - Deflection of Laminated Cellular Foam Strip

A natural extension of the technology involved in the laminated foam strip was to produce a flooring system for use in the upgrading of timber and concrete floors in refurbishment projects. Designs have been produced involving the use of open cell polyurethane foam as the resilient layer.(15) Such decks have limited airborne attenuation properties and additional treatment (16) is desirable in order to provide a balanced upgrade in terms of both airborne and impact sound reduction.

The question of stability of very thin boards is a major problem especially with high compliance resilient layers. This has been overcome in the design by incorporating a closed cell peripheral foam, 50mm wide, around two adjacent sides of each board so that each joint is supported by a low deflection strip as shown in Figure 8

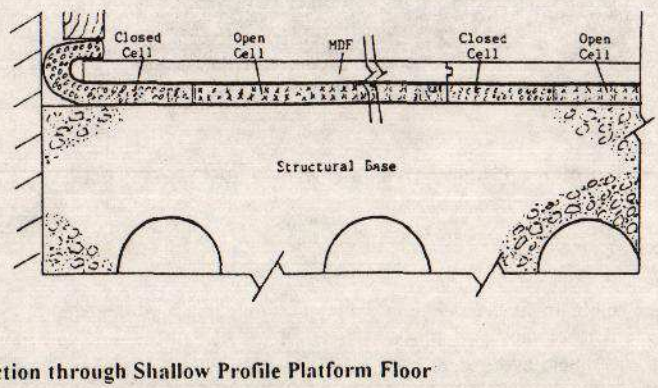


Figure 8 - Section through Shallow Profile Platform Floor

A shallow profile floor has been designed with both excellent walking stability and acoustic performance, giving an 18 dB weighted impact sound improvement as calculated in accordance with Annexe A of B.S. 5821:1984

4. A BROAD BAND ULTRASONIC FOAM ANALYSER (BUFA)

A BUFA system was developed at SHU by Langton and Deakin (3) in order to extend work being carried out on a contact system for broad band ultrasonic analysis of bone. The structural similarities between foam and cancellous bone were noted and the results of the investigation, although by no means conclusive, suggest that the possibility exists for developing an ultrasonic technique for foam characterisation.

A foam sample was placed between a high frequency speaker and a microphone and the speaker swept through a range of 15 kHz to 40 kHz. The amplitude of the transmitted signal was recorded using a spectrum analyser for different frequencies in the range. These signal amplitudes were then compared with those obtained with no sample present between speaker and microphone which were used as a reference. Subtracting this reference spectrum from that obtained with the foam in place gave the signal attenuation due to the foam. It was found (for all the samples used) that the attenuation characteristic obtained was linear over a portion of its spectrum and the gradient of this linear portion was taken to be the broad band attenuation index (BUAI) for the foam. Reproducibility of the BUAI for foams was found to be better than 4%.

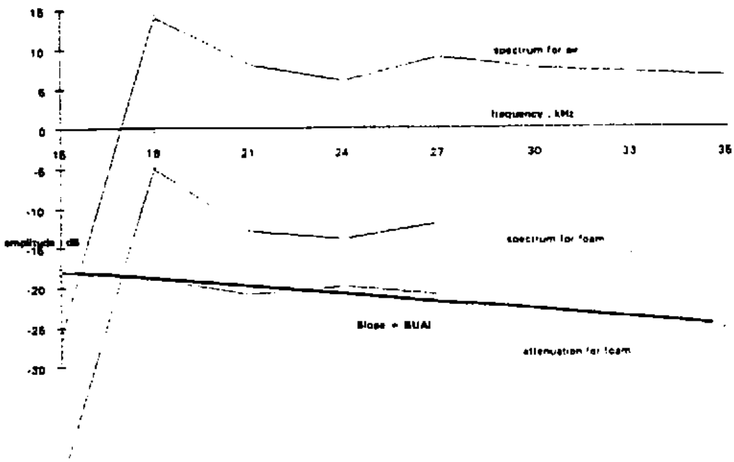
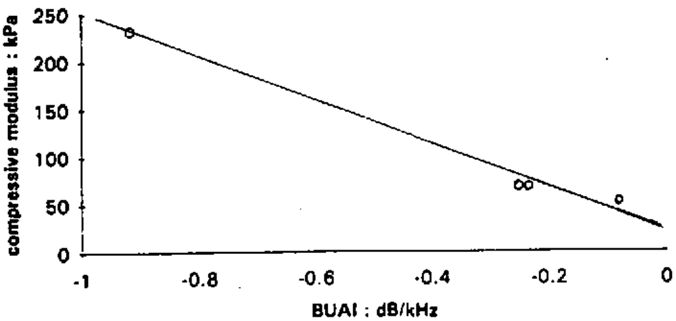


Figure 9 - Illustration of BUAI calculation

When compared with data from earlier studies on foam (17) it was found that there was a linear relationship between BUAI and Young's Modulus at small strains. Further tests showed a linear relationship between force at 70% compression and BUAI. Typical results obtained are shown below.

Compressive Modulus vs. BUAI



Maximum Force at 70% Compression vs. BUAI

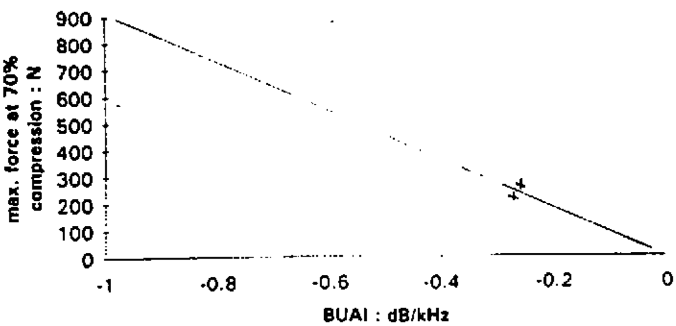


Figure 10
- Relationship between Compression and BUAI

CONCLUSION

Mechanical tests on foams will be conducted in order to classify them and determine their dynamic behaviour. Research has found that treating elastomer foams as one form of cellular material leads to interesting possibilties for investigating their classification and behaviour. An example is the use of equation solving software to calculate sress-strain relationships of layered arrays of of elastomer foam (18).

ACKNOWLEDGEMENTS

This work was financed under a Royal Society/Science and Engineering Research Council Industrial Fellowship in collaboration with A. Proctor Developments, part of the A Proctor Group, Blairgowrie, Perthshire.

REFERENCES

1 Hilyard, N C (ed) (1982) Mechanics of Cellular Plastics, Applied Sciences Publ. London
2 Determination of Dynamic Stiffness, ISO 9052-1, 1989.
3 Langton, C M et al. A Contact Method for the Assessment of Ultrasonic Velocity and Broadband Attenuation in Cortical and Cancellous Bone, Clin. Phys. Physiol. Meas. Vol. 11, 1990.
4 Gibson, L J & Ashby, M F. (1988) Cellular Solids, Pergamon Press
5 Gent, A N and Thomas A G, RubberChem Tech., 36, 597, 1963
6 Timoshenko, S P and Goodier, J N (1970) Theory of Elasticity, 3rd Edition, McGraw Hill
7 Mackenzie, R K, The Development of a Sound Absorbing Flooring System, Proc I.O.A. 169-174 (8) 1986
8 Mackenzie, R K, The Sound Insulation of Flooring Systems Incorporating Resilient Foam Strips, Proc. I.O.A. 53-61 (10) 1988
9 Mackenzie, R K, Sound Attenuating Floor Construction Incorporating a Polyether Foam Resilient Strip, U.K. Patent No 2196356, publication date 2 April 1991
10 Mackenzie, R K, Sound Attenuating Floor Construction Incorporating a Laminated Foam Resilient Strip, U.K. Patent No. 2192913, publication date 3 April 1991
11 Mackenzie, R K, Sound Attenuating Floor Construction, U.K. Patent No. 2214537, publication date 29 April 1992
12 Mackenzie, R K, Upgrading of Floors in Refurbishment Projects. Proc. I.O.A 301 - 308 (15) 1993
13 Mackenzie, R K, Sound Attenuating Laminated Strip, U.K. Patent Application, No 9012368.8, filing date 2 June 1990.
14 Mackenzie, R K. Sound Deadening in Panels and Like Building Structural Parts, U.K. Patent Application No. 2259131, filing date 21 August 1992
15 Mackenzie, R K. Floor Construction (Buildings). U.K. Patent Application No 9310312.5, filing date 19 May 1993
16 Mackenzie, R K. Improvement of Sound Insulation of Timber Floors : A Study of the Relative Significance of Mass, Resonance and Resilience in the System, Proc. I.O.A. 79-89 (8) 1986
17 Collier, P .The Design and Performance of Non Linear Vibration isolating Materials, PhD Thesis 1985.
18 Peleg, M. Calculation of the Compressive Stress-Strain Relationships of Layered Arrays of Cellular Solids Using Equation Solving Computer Software. Journal of Cellular Plastics, Volume 29, 1993.
19 Langton C.M.,Deakin, A J. Characterisation of Composite Materials Using Broadband Ultrasonic Attenuation, SHU internal report, 1992.