The measurement of the damping loss factor of gypsum plasterboard

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The damping loss factor of gypsum plasterboard has been determined from resonance bandwidth measurements over the frequency range from 35 Hz to 5 kHz. In the frequency range from 35 Hz to 600 Hz, the measurements of the damping loss factor of gypsum plasterboard were in the range from 0.013 to 0.020. Measurements at higher frequencies indicated that the damping loss factor of gypsum plasterboard is fairly constant across the measured frequency range. These results based on resonance bandwidth measurements were confirmed by measuring the decay rates from resonance.

1. Introduction

CSIRO has run a building acoustics laboratory on its Highett site in Melbourne since 1949. This laboratory used to conduct vibration damping measurements for the automotive industry using the Geiger Thick Plate Method. When Australian Standard AS 1937.10-1977 [1] was published, CSIRO withdrew from this measurement method because of the large number of measurements at non-ambient temperatures that the standard required. The apparatus still exists but unfortunately the driving electromagnet has been lost during one of several relocations. AS 1937.10-1977 neglects to point out that frequency doubling occurs because the electromagnet is not pre-polarized. This is not the case with the magnet and capacitive transducers used with the complex modulus apparatus.

In the early 1950s, Oberst et al. [2,3] at PTB in Germany developed the complex modulus apparatus (bending wave apparatus). Brüel and Kjær manufactured Oberst’s apparatus under licence. The instruction manual [4] for the apparatus in CSIRO’s possession is dated October 1959. The complex modulus apparatus type 3930 is listed in Brüel and Kjær’s 1974 master catalogue [5], but does not appear in the Brüel and Kjær 1983 master catalogue [6]. The bars onto which damping materials are bonded for testing in the complex modulus apparatus are known as Oberst bars.

When the author was developing theories for predicting the airborne sound insulation (sound reduction index or sound transmission loss) of gypsum plasterboard walls, he needed to know the damping loss factor of gypsum plasterboard. He organised two of his staff to measure the damping loss factor of gypsum plasterboard using the complex modulus apparatus. This paper describes those measurements. The complex modulus apparatus was also used in the preliminary stage of CSIRO’s study of the active attenuation of airborne sound passing through the glass in windows.

CSIRO also makes commercial measurements of the damping loss factor using the complex modulus apparatus. Using an oven and a freezer, these measurements can be made at a number of different temperatures. These measurements are usually conducted for automobile manufacturers or their vibration damping material suppliers. They are usually conducted in compliance with the individual automobile manufacturer’s test specification. CSIRO has also conducted sound absorption measurements on under bonnet liners for automobiles, flow resistance measurements on automobile lining materials and airborne sound insulation measurements on railway train carriage doors.

2. Principle of Measurement

A suitably mounted bar of test material is vibrated by driving it with a sinusoidal signal. Non-contact magnetic transducers are normally used to vibrate the test bar. For non-magnetic materials (such as plaster), it is necessary to attach small ferromagnetic disks adjacent to the transducer. The relative amplitude of vibration can be measured using a second non-contact transducer (magnetic or capacitive).

The loss factor of the material can be determined by one of three methods. The first method is the measurement of the rate of increase of vibration amplitude (rise time method). The second method is the measurement of the rate of decrease of vibration amplitude (decay rate method). The third method is the measurement of the bandwidth (at -
3 dB points) of the resonance (resonance bandwidth method). This latter method was the one adopted for most of these measurements because it does not place high demands on instrument settling and response times. The damping loss factor is calculated directly as the ratio of the (-3 dB) bandwidth to the resonant frequency.

\[ \text{Loss factor} = \frac{f_{\text{upper}} - f_{\text{lower}}}{f_{\text{resonance}}} \]

The bar should not be overdriven, since this can modify the atomic structure of the material being tested and can cause the bar to go into non-linear loss mechanisms. In practice this means applying just sufficient drive voltage to enable the measurement to be performed.

The basic theory for vibrating bars is given by Rayleigh [7]. For a fixed/free bar the modal frequencies of vibration are inversely proportional to the square of the free length and directly proportional to \( x_i \), where \( x_i \) (i=1,2,3,...) are the solutions of the equation,

\[ \cos(x) \times \cosh(x) + 1 = 0. \]

The first seven roots are given in Table 1.

<table>
<thead>
<tr>
<th>i</th>
<th>( x_i )</th>
<th>((x_i/x_1)^2)</th>
<th>Resonant frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.8751</td>
<td>1.000</td>
<td>37 Hz empirically</td>
</tr>
<tr>
<td>2</td>
<td>4.6940</td>
<td>6.267</td>
<td>232 Hz (235 Hz empirically)</td>
</tr>
<tr>
<td>3</td>
<td>7.8547</td>
<td>17.547</td>
<td>649 Hz (667 Hz empirically)</td>
</tr>
<tr>
<td>4</td>
<td>10.9955</td>
<td>34.386</td>
<td>1272 Hz</td>
</tr>
<tr>
<td>5</td>
<td>14.1372</td>
<td>56.843</td>
<td>2103 Hz</td>
</tr>
<tr>
<td>6</td>
<td>17.2788</td>
<td>84.914</td>
<td>3142 Hz</td>
</tr>
<tr>
<td>7</td>
<td>20.4204</td>
<td>118.999</td>
<td>4388 Hz</td>
</tr>
</tbody>
</table>

The last column of this table gives the predicted modal frequencies based on the empirical value for the first mode. A plot of the modal shape for the first few bar modes was also produced. This output allowed the nodal points to be avoided when placing mu-metal (ferromagnetic) disks on each specimen bar.

3. Material Tested

A sample of 10.2 mm thick gypsum plasterboard was obtained, from which three specimen bars were cut. The dimensions of each of the three specimens were 10.2 mm thick by 11.9 mm wide by 301 mm long.

4. Instrumentation

The complex modulus apparatus (Brüel and Kjær type 3930) was used. This equipment is discontinued by Brüel and Kjær and the information in the manual [4] is rather dated. Additional information was found in the Brüel and Kjær Technical Reviews [8, 9]. The complex modulus apparatus essentially is a rigid metal stand which enables a test specimen to be clamped firmly at either end (usually the upper end) or at both ends and allows driver and pickup transducers to be presented to the test bar. To enable the plaster specimens to be fitted into the apparatus, approx. 0.75 mm was machined off the face of one holder.

The test signals employed were sine-waves generated by a Hewlett-Packard synthesizer/function generator (type 3325A), using its high voltage output option. Initially we used a Rotel audio power amplifier (type RA 820BX) to boost the signal before presenting it to the magnetic transducer (Brüel and Kjær type MM0002). The power amplifier was later discarded when the location of the magnetic transducer was changed to a more efficient position. To enable the bar to react to the magnetic transducer, a small mu-metal disk was glued to the bar adjacent to the transducer.

To detect the amplitude of vibrations of the test bar, a capacitive transducer (Brüel and Kjær type MM0004) was used. A second metal disk was glued to the bar 190 mm above the free end to form the second plate of the capacitor and a very fine conducting wire was soldered to it and earthed, to complete the circuit. The effect of various air-gaps was tried for both transducers before standardising on 1.0 mm for the magnetic transducer, and 0.5 mm for the capacitive transducer.

The output from the capacitive transducer was amplified by a Brüel and Kjær preamplifier. Initially a Brüel and Kjær type 2615 was used, but in efforts to improve the signal to noise ratio this was replaced by a Brüel and Kjær type 2619, and later by a Brüel and Kjær type 2660 (on its +20 dB gain setting). The signal from the preamplifier was then passed to a measuring amplifier (Brüel and Kjær type 2607). The 2607 could have been used to manually
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to measure the bar's relative vibration amplitude, but it was found to be much more convenient to take an amplified signal from it and to measure it remotely using an GPIB bus controlled multimeter (Hewlett-Packard type 3478A). The DC output from the 2607 was used because it enabled the multimeter to be used on its fastest measuring rate.

The overall measurement procedure and control of the Hewlett-Packard synthesizer and Hewlett-Packard multimeter was automated via a computer program developed for this task. Currently a Hewlett-Packard Type 35670A two channel dynamic signal analyser with the swept sine measurement option is used instead of the synthesizer, multimeter and computer.

4.1 Early arrangement

Initially the bars were set-up, as suggested in the Bruel and Kjaer Technical Reviews [8, 9], with the magnetic driver acting on a mu-metal disk glued to the bottom (i.e. axially) of the test specimen. With this arrangement, the bar is induced to vibrate by virtue of inevitable asymmetries in the magnetic field produced by the transducer [10]. This is a relatively inefficient drive method, since it relies on second-order magnetic force effects rather than the primary magnetic attraction (i.e. between transducer and mu-metal disk). Presumably, if the field were ideally symmetric, then no lateral forces would be present, so the bar would not tend to be excited.

Apart from the inefficient drive method, a second disadvantage of this arrangement arises from the proximity of the drive transducer to the free end of the bar. There is insufficient space available for the capacitive pick-up transducer to be placed at this optimal point to detect bar movement.

![Graph](image)

Figure 1. Initial damping loss factor measurements on gypsum plasterboard as a function of resonance frequency.

4.2 Improved arrangement

While obtaining some widely scattered results with the above arrangement, more recent information regarding the measurement of loss factors was obtained in the form of an ASTM Standard [11], plus the (previously referenced) Bruel and Kjaer Application Note [10]. The Bruel and Kjaer application note was found to offer more practical advice than the ASTM standard, and recommended a fundamental change in the location of the magnetic driver. Accordingly, the magnetic transducer was located transversely to the bar at a distance below the clamped end (preferably at an antinode). The capacitive pick-up transducer was used adjacent to the free end (probably the ideal position). After making these changes, the magnetic driver transducer was much more effective since it made use of the primary magnetic force rather than second order effects. Also, because the pick-up transducer was at a more advantageous location, it gave a stronger signal.

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5. Measurement procedure

5.1 Early set-up

The damping loss factor can be measured in three ways using the complex modulus apparatus: (a) measurement of the bandwidth of the resonance mode, (b) measurement of the rate of build-up of vibrations, and (c) measurement of the decay rate of vibrations. All three methods were tried, with (a) seeming to offer the most promise of consistent results. Despite using the multimeter at its maximum speed, reservations were held regarding the response time of the detection instrumentation for methods (b) and (c). With method (a), response time is not an issue and the basic measuring sequence used was:

Set the Frequency,
Provide a Settling Time,
Measure the Response.

Frequency was incremented geometrically (i.e. $f_{i+1} = \text{factor} \times f_i$) rather than arithmetically. The direction of sweep across each resonant frequency was alternated between runs. Various frequency incrementing factors were tried. For initial scans of the bar, to locate resonance frequencies, values around 1% were used. For actual production runs, a much finer frequency step seemed necessary, usually 0.05% to 0.1%. The settling time chosen depended on the modal frequency being investigated; 3 s at 35 Hz, and 0.5 s at 650 Hz and above was typical.

From the stored data (voltage and frequency), the program determined the half-power (voltage-squared domain) frequencies by linear interpolation. The resonant frequency was calculated as the geometric mean of the two half-power frequencies. The loss factor was then found by applying the simple equation:

$$\text{Loss factor} = (f_{\text{upper}} - f_{\text{lower}})/f_{\text{resonance}}$$

Using this set-up, we obtained somewhat inconsistent results for loss factor varying between 0.01 and 0.04 (see figure 1).

![Graph showing damping loss factor as a function of driving voltage.](image)

Figure 2. Damping loss factor as a function of driving voltage.
5.2 Improved set-up

While attempting to understand why we were getting scattered results, we discovered ASTM Standard E 756-83 "Standard Method for Measuring Vibration Damping Properties of Materials" [11]. Upon reading it however one finds that it glosses over some of the practical difficulties of measurement. We also discovered the previously mentioned Bruel and Kjær Application Note "Measurement of the Complex Modulus of Elasticity: A Brief Survey" (probably published about 1973) [10] which was considerably more pithy than the ASTM standard. A different measuring arrangement is recommended by it. The magnetic driver transducer is located transversely to the bar at a distance below the clamped end (preferably an antinode); the capacitive pick-up transducer is used adjacent to the free end (probably the ideal position).

After changing the transducers to these more effective positions, we started getting more consistent results. One finding was that results depended on the voltage going to the magnetic driver; the curve of loss-factor versus driver voltage is U-shaped, with valid results occurring at the minimum of the curve (see figure 2). At very low driver voltages, one fails to excite the resonance peak sufficiently above the noise-floor of the general response curve (i.e. one cannot obtain "clean" -3 dB points). At high driver-voltages, the problem arises from "over-driving" the bar; the bar probably goes into non-linear damping, and the loss factor increases. For low frequency modes, it is easy to overdrive the bar, so measurements need to be made at low driver voltages; whereas for high frequency modes high driver-voltages are needed the raise resonant peaks above the surrounds of the response curve.

Measurements were made with the three specimens over the first three modes, and gave moderately consistent values for loss factor in the range from 0.013 to 0.020 (see figure 3).

![Graph showing damping loss factor measurements](image)

**Figure 3.** Improved damping loss factor measurements on gypsum plasterboard as a function of resonance frequency.

Measurements up to 5 kHz were then attempted by shortening the bars (clamping them closer to free end) and by driving them at higher modes (up to the 7th). Earlier attempts made with the "early set-up" had failed because of inefficient transducer locations. The measurements again indicated that loss factor can be considered to be reasonably constant over the measured frequency range (30 Hz - 5000 Hz).
6. Confirmation of Resonance Measurements using Decay Rate Method

By this stage, a large number of measurements of loss factor had been taken from the three specimens over a range of frequencies from 35 Hz to 5 kHz. It was decided to see if agreement could be obtained when using one of the other measurement approaches which was available. A level recorder was used and after various trials, was able to measure loss factors for the specimens over the same frequency range of about 0.013.

7. Conclusions

The damping loss factor of gypsum plasterboard in the frequency range from 35 Hz to 5 kHz is in the range from 0.013 to 0.020 when measured by the resonance bandwidth method. The decay rate method gives a value of 0.013 at the bottom end of the range from the resonance bandwidth method. Table 11.4 of Vér and Holmer [12] gives a range 0.01 to 0.03 for the damping loss factor of gypsum plasterboard. Vér and Holmer comment that the range of values of damping loss factor are based on limited data, and that the lower values are typical for the material alone while the higher values are the maximum values observed on panels in place. Thus the measurements described in this paper lie within the range of values given by Vér and Holmer. In his theoretical work on the prediction of airborne sound insulation, the author has found it necessary to use 0.03 or 0.04 for the damping loss factor of gypsum plasterboard, in order to obtain good agreement with experimental measurements of sound insulation.

References


Acknowledgements

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PREFACE

It is with great pleasure that I welcome you to the 10th Asia Pacific Vibration Conference (APVC 2003) being held at the Royal Pines Resort, Gold Coast, Australia, on November 12-14, 2003. The location is stunning and is a magnificent venue for the 2003 meeting. More than 300 authors from 10 countries have contributed over 160 papers to be presented over the three days of the conference.

The APVC is an international conference held biennially (once every two years) and deals with the presentation and publication of outputs of research and development activities in aspects of dynamics, control, sound and vibration, condition monitoring and related disciplines. In general, academics, practitioners and scientists from around the world come together to share their knowledge in this important discipline that impacts on many aspects of our daily life. All full papers published in these proceedings have been refereed by specialist members of a peer review panel for technical merit. It will be noted that some papers contain grammatical errors but these have been published regardless. The Editors have resorted not to edit these in detail given timing constraints in the publication process.

The vision for the APVC originated in Tokyo in July 1985 during a JSME Vibration Conference, when the conference chairman, Prof T Shimogo, organised a special session which involved the participation of scholars from China, Korea and Singapore to discuss the specific need for an Asia based vibration conference. A series was thus borne which in 1989 was broadened and titled, the Asia Vibration Conference. The title was expanded to include the terms, "Asia-Pacific" at the fourth meeting held in Melbourne, Australia in 1991 to reflect the participation of Australia, New Zealand and other countries of the Asia-Pacific rim. The following has grown since.

APVC Sponsorship: I would like to gratefully acknowledge the support of Queensland University of Technology and the Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM) for their valuable sponsorship of APVC 2003. The conference is also co-sponsored by the Chinese Mechanical Engineering Society, The Institution of Engineers Australia, The Korean Society of Mechanical Engineers and The Japan Society of Mechanical Engineers.

A state-of-the-art exhibition will also give suppliers of equipment and services an excellent opportunity to showcase their new products in this growing market. We are grateful to National Instruments, Bruel & Kjaer Australia, Poly Flex Group, Davidson and QUT/CIEAM for their participation in our 2003 Exhibition.

Vote of Thanks: I am sure you will join me in thanking all the members of the APVC 2003 Organising Committee for the enormous effort they have contributed to making this conference a success. Of special note, is Chair of the Organising Committee, Associate Professor Andy Tan, the Vice Chair, Dr Lin Ma, and Dr Vladis Kosse for managing the technical review process. Also thanks to Zoe Holbeck and Tiah Miller from QUT’s Commercial Services Office for being the conference and events coordinator and Dr Tierang Liu, Mr Sun Yong and Dr Zhang Sheng for laying out the proceedings.

In closing, I would like to invite you to enjoy APVC 2003 and the Gold Coast of Australia. You will be able to sample some of the delights of this region through our conference and the conference dinner at the Paradise Country. However, there is a whole lot more to see and do around the Gold Coast. I trust you will take time out after the conference to enjoy what this region and the state of Queensland offers.

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