

ISSN 0815-9793

# JANM

JOURNAL of the AUSTRALIAN ASSOCIATION of  
MUSICAL INSTRUMENT MAKERS



**VOL. IX NO.1.      MARCH 1990.**

Registered by Australia Post  
Publication No. NBH6887

a more detailed study but this was denied as they felt in Committee that this area had been fully documented! If you would like more information on items in this article please write to the Southern Arts Council, not myself.

\* George Keysler Travels Through Italy  
J. Scott At The Black Swan in Pater-noster Row, 1758 London.

[Reprinted with permission from the 1988 Tiverton Conference]

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## AN EVALUATION OF THE LUCCHI ELASTICITY TESTER

by J.E. McLennan

### SUMMARY

The values of Young's Modulus obtained using the Lucchi Elasticity Tester have been compared with published values for some common materials and also compared with the results of other test methods. Agreement was obtained for the common metals but differences were found for plastics and wood. The Tester gave values higher than published figures for the plastics tested and higher values for wood compared with those from a static method.

Although more research is needed, careful use of the Tester gives results that can be used to assess the quality of resonant tonewood. Some care is needed in interpreting transverse values of elasticity as shear deformation appears to be significant in other test methods.

### INTRODUCTION

The single most important parameter of soundboard material for musical instruments is the radiation constant. This should be as high as possible to give maximum sound output. This constant is obtained by dividing the velocity of sound in the material by the density.

Another parameter with an effect on sound output is damping. This should be kept as small as possible. It is made up of two parts: the inherent internal friction of the material and the damping introduced by assembling the instrument. The latter and fitting strings and tensioning them always increases the damping.

The radiation constant can be determined from measured values of the velocity of sound in the material and the density. The latter is readily obtained from the weight of an accurately prepared rectangular prism, cut from the waste part of the soundboard, and its dimensions. The velocity of sound can be found from the resonant vibration of a beam of the material or the transit time for an ultrasonic wave to pass through the material. The Lucchi Elasticity Tester measures the latter and is the subject of this study.

Sound wave propagation in homogeneous materials is considered to be well understood. Propagation in composite materials is not well understood. Wood is thought to behave like a layered composite material. This idea is supported by its microstructure and the orthotropic nature of its physical properties. It has been suggested that very high frequency sound waves travelling along the grain see the structure as a waveguide and when travelling across the grain, as a band pass filter. Bedford et al [1] summarise the present understanding in composite materials. To a first approximation, when the wavelength is long compared with the structural periodicity in the direction of propagation, dispersion does not occur and the phase [wave] and group velocities are equal. This means that the signal remains unchanged during its passage through the material and valid results can be obtained.

The measurement of sound velocities and hence elastic constants in spruce and maple, has been done by Bucur [2] in recent times using 1MHz frequencies.

The present study was aimed at determining the signal frequency of the Lucchi Elasticity Tester and evaluating its use on various materials and comparison with results from static and resonant vibration methods.

#### THE ELASTICITY TESTER

The Tester emits an ultrasonic pulse from a transducer placed in contact with a sample and the pulse is detected by a receiver after traversing a known distance. The transit time is displayed on a digital readout. Coupling is achieved at the transmitter by a layer of soft rubber. A certain pressure is required between the transmitter/sample/receiver and is found with the aid of a calibration bar of Perspex and a specified transit time. This pressure is maintained for all subsequent readings. The transmitter and receiver are manipulated while maintaining the desired pressure to achieve a steady minimum reading of the time.

The time is expressed in microseconds [ $\mu$ s] so that:

$$\text{Sound velocity [km/s]} = [\text{length [mm]}]/[\text{time } [\mu\text{s}]],$$

and with a knowledge of the density, the elastic modulus in the direction of propagation can be calculated using the equation

$$\text{Modulus [N/m}^2\text{]} = \text{Velocity}^2 \text{ [m/s]}^2 * \text{Density [kg/m}^3\text{]}$$

The Tester has rechargeable Ni-Cd batteries and is supplied with a charger and backup batteries.

Two holders were made for the transducers, one spring loaded so that the holding pressure could be reproduced and maintained easily during successive readings. These were used for all readings.

## EXPERIMENTAL DETAILS

### Surface Preparation

Surface preparation was found to be important in that a smooth plane surface was necessary for proper transmission of the signal and its detection. A rough sawn surface on wood as typically found on tonewood billets, particularly on the endgrain, was unsatisfactory. The surface had to be planed smooth or fine sanded. Difficulty in obtaining a consistent reading is the result of a rough surface.

### Signal Frequency and Examples for Mild Steel and Spruce

The signal from both the transmitter and the receiver were recorded on a digital storage oscilloscope and subsequently plotted on graph paper. Figure 1 shows both signals for the Perspex calibration bar, the transmitted signal above that received. The received signal was much weaker than the transmitted signal. The scaling for the former was 200 times that for the transmitted signal in this case. The time in 0.1 microseconds is counted from the initial onset of the transmitted signal until stopped by the receiver. The waveform of the transmitted signal was remarkably reproducible in every detail in all the tests done. The signal at the receiver was different in form and amplitude but showed a general similarity with different materials.

The two signals in Figure 1 were analysed to determine their frequency content. The result is shown in Figure 2. The starting spike on the transmitted signal was excluded as shown and the analysis yielded two main frequency bands centered around 60 kHz and 120 kHz. The width of the bands is partly accounted for by the small number of sample points. The same can be said for the band in the analysis of the received signal which is also centered at 60 kHz and is a well defined peak.

While the transmitted signal maintained a high reproducibility, the signal after transmission showed evidence of multiple reflection although the form of each "packet" remained constant. This is illustrated by the example for mild steel shown in Figure 3. The vertical scaling in this case for the received signal was 10 times the input signal indicating lower damping than in Perspex.

Signal traces are shown in Figures 4, 5 and 6, for the three orthogonal directions in a rectangular block of spruce. The vertical scaling was the same as that for Perspex. The block was 242 mm [L direction], 60.5 mm [R direction] and 23.5 mm [T direction]. The traces are similar in all three directions with some overlapping of the first reflected signal in the L direction.

### Measurement of Sound Velocity in a Range of Materials

Some common materials in rod form were selected for sound velocity measurement. The ends were prepared in most cases by fine turning in a lathe. Table 1 shows the results obtained with comparison values taken from Kaye and Laby [3].

TABLE 1  
SOUND VELOCITY IN COMMON MATERIALS

Material	Density, d Kg/m <sup>3</sup>	Velocity of Sound, c m/s		Young's Modulus, E *10 <sup>10</sup> N/m <sup>2</sup>	
		K & L	Expt <sup>1</sup>	K & L	Expt <sup>1</sup>
Brass 60:40	8400	3500-3650	3598	10.0	10.9
Mild Steel	7860	4700-5200	5137	20.0	20.7
Hi C Steel	7840	-	5277	20.9	21.4
Aluminium	2700	5100	5140	7.05	7.1
Glass [Soda]	2500	5000-5300	5226	6.5-7.8	6.8
Perspex	1190		2195	0.3*	0.57
HD Polythene	950		1449	0.1*	0.2
Calibr. Bar	1190		2277	0.3*	0.62

\*From Materials Data Book: E.R. Parker, McGraw-Hill, 1967

It can be seen that for the common metals and glass, the experimental values of the velocity of sound fall within the accepted ranges, and the calculated elastic moduli agree well with published data as would be expected. These materials would be considered to have homogeneous structures on a microscopic scale.

No sound velocity values have been found for the plastics quoted and the values of Young's Modulus given in the literature are about half those calculated from the sound velocities measured.

#### Comparison of Elastic Moduli Determined by Three Methods

A further comparison of elastic moduli was made using two other experimental techniques, [a] the static deflection of a simply supported beam with centre loading, and, [b] the resonance frequency determination for the same beam in its lowest vibration mode.

The equation for Young's Modulus for the deflection of a flat rectangular section beam of the material simply supported and loaded at the centre, is given by:

$$E = [M * g * L^3] / [48 * I * y] \quad [N/m^2] \text{ Pascals}$$

where E is Young's Modulus,  
M is the mass load, [Kg],  
g is acceleration due to gravity [9.81 m/s<sup>2</sup>]  
L is the distance between supports,  
I = [bd<sup>3</sup>/12] is the section modulus, [m<sup>4</sup>], and  
y is the deflection due to Mg.

The distance between supports was 0.135 m; the beams were of the order of 0.040m wide and 0.001-2m thick for the metals and 0.003-4m thick for the non-metals. Masses up to 1 Kg in small increments were used to determine the deflection curve, the slope of which gave Mg/y.

The resonance method involved the same beam which was suspended over a speaker on string supports at  $0.224L$  from each end. A small magnet [0.15g] was mounted in the centre of the beam and a coil, placed over it and connected to a C.R.O. via a preamplifier, monitored the vibration amplitude. A sinewave from a signal generator was fed to the speaker and swept slowly to the lowest frequency position with maximum amplitude. The frequency was read from a counter connected across the generator/amplifier output. An equation given by Haines [4] was used to calculate the elastic modulus.

$$E = 0.946 * d * f^2 * L^4 / T^2$$

where  $d$  is the material density,  
 $f$  is the resonant frequency,  
 $L$  is the length of the beam,  
 $T$  is the beam thickness.

Finally, the same beams were used for velocity measurements with the Elasticity Tester. The recommended calibration was applied and the results calculated using the equation,

$$E = c^2 * d$$

where  $c$  is the velocity of sound in the material [m/s]

$d$  is the density of the material [ $\text{Kg/m}^3$ ]. Since the beams had been accurately dimensioned, they were weighed and the density calculated from the measured volume. The results from these three techniques are shown in Table 2.

TABLE 2

## ELASTIC MODULI OF MATERIALS DETERMINED BY THREE METHODS

Material	Density $\text{Kg/m}^3$	Young's Modulus $*10^{10}[\text{N/m}^2]$		
		Static Bending	Resonant Vibration	Sound Velocity
Aluminium	2746	7.48	7.94	7.3
Mild Steel	7932	22.65	21.8	22.0
Perspex [3mm]	1192	0.335	0.504	0.679
Perspex [6mm]	1192	0.309	0.516	0.663
Spruce [L]	467	0.995	1.41	1.45
Spruce [R]	473	0.043	0.0565	0.067
Spruce [R]	473	0.049	0.065	0.072
Maple [L]	553	0.818	0.946	0.946
Maple [R]	570	0.135	0.151	0.165

DISCUSSION

The discussion centres around three things: the frequency used to determine the velocity of sound, the comparison of experimental Young's Modulus with published values and with other methods of determination.

In the Elasticity Tester the sound waves are presumably longitudinal compressional. Interaction is possible when the wavelength is of the same order as the spacing between growth rings. For the frequency of 60

kHz used, the wavelength is more than 10 times the spacing for most sound velocities and spacings encountered in acoustic soundboards. The relation, wavelength =  $c/f$ , leads to the following values in Table 3 for the approximate wavelength as a multiple of ring spacing, for typical values of ring spacing and sound velocity.

TABLE 3

Velocity (c) (m/s)	Number of Rings equal to the Wavelength at ring spacings of		
	1 mm	2 mm	4 mm
4250	60	30	15
3250	50	25	13
2250	35	15	7
1250	20	10	5
750	12	6	3

For comparison, at the frequency of 1 MHz used in ultrasonic studies of elastic constants, a velocity of 4250 m/s gives a wavelength of 4 mm, and at 1250 m/s a wavelength of 1 mm. A wavelength of about 10 times the ring spacing would be considered desirable.

In looking at the elastic moduli, the agreement is good between values published for some common metals and the experimentally determined values shown in Table 1. However, in the same table, the values for Perspex and HD Polythene show a large discrepancy between published and experimental results. An explanation is not possible without further study.

When comparing values of the elastic modulus determined by three different methods, the values for Aluminium and Mild Steel show reasonable agreement between the three methods, but for Perspex the value from the static test is much lower than from the two dynamic tests. This may be related to the discrepancy noted above.

In the case of Spruce and Maple, the results from the static test are also lower than for the other two tests. In the longitudinal direction agreement is good between the two dynamic tests, but is less good in the case of the crossgrain samples, and the static test results are again lower. Kollman and Cote[5] in their table 7.3 quote values of Young's modulus for Spruce found by static and vibration methods. These are given below in Table 4 together with values corrected for shear. They state that frequency did not significantly influence the measurements.

TABLE 4

Property	Young's Modulus *10 <sup>10</sup> [N/m <sup>2</sup> ]	
	Density 501 Kg/m	[Corrected for Shear]
E [Static bending]	1.485	1.68
E [Trans. vibration]	1.587	1.75
E [Longl. vibration]	1.771	not applicable

These values show a similar trend to the results of this study. It appears that a correction for shear is required for the non-metallic materials in this study.

An attempt to measure the shear modulus of spruce was made using a torsion pendulum. The specimen was about 0.65 m long and 4 mm square. It was made the suspension on which hung the inertia bar. The specimens were cut with their axes in the longitudinal and transverse [radial] directions respectively. The shear modulus is given by the equation:

$$G = 8 \pi^2 I L [f/r^2]^2$$

where I is the inertia attached to the specimen,  
L is the specimen length,  
r is the specimen radius, and  
f is the frequency of oscillation.

Values of the shear modulus, G, for spruce and perspex were found as shown in Table 5. Those for spruce were of the same order as values determined by Haines [6] and Bucar [7] the variability of wood can account for differences. There is a need with wood to be quite specific with regard to direction and which elastic constant is being considered.

TABLE 5

DETERMINATION OF SHEAR MODULUS

Specimen [axis]	Shear Modulus *10 <sup>10</sup> [N/m <sup>2</sup> ]	
	This Study	Haines [6]
Spruce [L]	0.096	0.084
Spruce [R]	0.029	0.0054
Perspex	0.183	

The difference in results for spruce [R] could be connected with the elastic constants acting.

While for spruce and maple the static bending method gave lower values for Young's Modulus, the resonant beam and sound velocity method gave very good agreement [Table 2]. However there were significant disagreement between the resonant beam and sound velocity method for transverse specimens. The difference was about 10%. For these transverse specimens with the length in the radial direction, the width in the longitudinal direction and the thickness in the transverse direction shear may account for the differences.

CONCLUSION

Within the limits of accuracy set by the operating conditions in terms of surface preparation and the manipulation of the transducers to obtain the lowest steady transit time, it would appear that useful measurements of Young's Modulus may be made with the Lucchi Elasticity Tester. The choice of signal frequency, 60 kHz, not far above the high acoustic region would appear to avoid the risk of serious wave dispersion effects. Being longitudinal compressional waves, shear effects are avoided and a Young's Modulus value under near operating conditions for tonewood would seem to be obtained.

It would appear that for wood and plastics, the determination of Young's

Modulus by bending methods requires that shear deformation be taken into account.

For spruce and maple good agreement was obtained for longitudinal specimens between the dynamic tests, transverse vibration and sound velocity measurement. With transverse specimens sound velocity measurements, which give the higher value, are probably more correct in the context of the action of soundboards.

#### ACKNOWLEDGEMENTS

I wish to thank Mr. R.W. Goodhew and Mr. P.C. McLauchlan from Electrical and Computer Engineering at the University of Newcastle for assistance in obtaining the signal waveforms and also Mr. P.W. McNabb for the frequency analysis.

#### REFERENCES

1. Bedford, A., Drumheller, D.S. & Sutherland, H.J. *Mechanics Today*, Vol.3, ed. S. Nemat-Nasser, Pergamon, 1976.
2. Bucar, V. *JCAS* No.47, May 1987, 42.
3. Kaye, G.W.C. & Laby, T.H. *Physical and Chemical Constants*, Longmans, Green & Co. 1944.
4. Haines, D.W. *CAS Newsletter*, No.33, May 1980, 19.
5. Kellmann, F.P. & Cote, Jr., W.A. *Principles of Wood Science and Technology*, George Allen & Unwin, 1968.
6. Haines, D.W. *CAS Newsletter* No.31, May 1979, 23.
7. Bucar, V. *ibid.*



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