Note

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Measurement of Young's Modulus by the Transient Longitudinal Vibration of Wooden Beams Using a Fast Fourier Transformation Spectrum Analyzer [*1]

Nobuo SOBUE[*2]

FFTスペクトルアナライザを用いた木材の過渡的縦振動によるヤング率測定[*1]

祖父江信夫[*2]

木材の木口面を打撃したときに発生する打音を FFT スペクトルアナライザによって周波数分析し，得られた共振周波数から木材のヤング率を測定する方法について検討した。打音によって木材の過渡的な縦振動を検出することにより，簡単で高感度の振動の検出が可能となり，小試験体および実大構造材で 6～7 次までの共振が確認された。

試験体の長さを変えることにより，広い周波数範囲に渡たるヤング率を容易に測定することができ，ベイスギとアガチスでは 2 kHz～40 kHz の範囲でヤング率はほぼ一定値を示した。

FFT スペクトルアナライザを用いた打音分析によるヤング率の測定は，小試験体のみならず実大の構造用材にも容易に適用できることが確かめられた。

A tap method to measure the Young's modulus of wood by transient longitudinal vibration was investigated. Small clear beams and commercial construction lumber were tapped with a small hammer, and the tap tones were analyzed by a FFT (Fast Fourier Transformation) spectrum analyzer to identify the resonance frequency.

A simple and sensitive detection of the vibrations by the tap tones was accomplished, and the resonance frequencies were obtained until the 6th or 7th vibration mode in both small beams and in commercial lumber.

By changing the length of the beams, the Young's modulus in a wider frequency range of 2 to 40 kHz easily was obtained. The Young's moduli of western redcedar and agathis were almost constant in this frequency range.

The tap method using a FFT spectrum analyzer was feasible not only for small beams but also for construction lumber of commercial size in obtaining their Young's moduli.

1. INTRODUCTION

The Young's modulus measured by longitudinal vibration is useful because it is not affected by the shear and rotatory inertia effects which are inevitable in flexural vibration. Some longitudinal vibration methods have been applied to wood, for example, the steady-state resonance method (Tonosaki and others,1) Kamioka and Kataoka2)), the stress-wave method (Dunlop,3) Marra and others,4) Gerhards5)) and the ultrasonic velocity method (Bucur6,7)).

The tap method proposed in this work is similar to the stress-wave method in tapping a beam, but

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[*2] 名古屋大学農学部 Faculty of Agriculture, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464, Japan

it differs in the point where the instantaneous frequency analysis of the transient resonance vibration is made by a FFT (Fast Fourier Transformation) spectrum analyzer.

The rapid measurement of the Young's moduli of short beams and commercial construction lumber was investigated.

2. MATERIALS AND METHOD

The experiment was made on short beams of hinoki, buna, shirakashi, rosewood, western redcedar, meranti, and agathis, 1 cm × 1 cm × 40 to 90 cm, and also on five pieces of 2 × 4 in. dimension lumber and twelve pieces of construction lumber for traditional Japanese houses, 9 cm × 9 cm × 3 m to 10.5 cm × 10.5 cm × 4 m.

Each short beam was supported lightly and horizontally by the fingers at the center of the beam, and the commercial construction lumber was laid horizontally on a rubber piece at the center of the beams, while they were tapped with a small steel hammer at an end of the piece. The tap tone was detected by a microphone at the other end of the beam.

The resonance frequencies of the tap tone were identified by a FFT spectrum analyzer, and the Young's modulus of free-free longitudinal vibration was calculated according to the vibration theory of elastic bodies.[8]

The accuracy of the frequency measurement by the FFT analyzer was one by eight-hundred of the full scale range of the analysis.

3. RESULTS AND DISCUSSION

3.1 Application to short beams

The intensity of the power spectrum decreased remarkably with an increase in the number of the vibration mode as shown in Figure 1(a). However, by the second differential operation on the power spectrum, the peak intensities at higher vibration modes were raised as shown in Figure 1(b), and resonance frequencies were identified until the 7th vibration mode.

A beam was supported at its center in this work. Therefore, to clarify the effect of the support of a beam on the resonance frequencies of the higher vibration modes, a beam was supported at the nodal points of seven vibration modes, and the measured resonance frequency for each vibration mode was compared with what was identified from the tap tone obtained by supporting the beam at its center. Both frequencies coincided within the experimental error; nevertheless, the center of the beam coincided with the loops of the even-numbered vibration modes. Accordingly, there was no significant effect of the support position of a beam on the measured resonance frequencies.

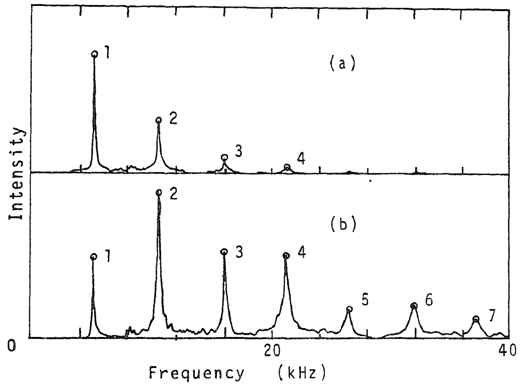

Fig. 1. Typical power spectrum of longitudinal vibration.
(a) Original power spectrum. (b) After differential operation on the original spectrum.
Note: Specimen was a clear short beam of keyaki.

The Young's moduli were almost constant against the number of the vibration mode as shown in Figure 2. The slight change of the Young's modulus is probably due to such natural defects as local grain distortion.

Because the deflection of the steady-state longitudinal vibration is very small, the measured frequency by this method does not exceed 15 kHz. However, by the tap method using a FFT analyzer the measurement in a wider frequency range is made easily.

Figure 3 shows the Young's moduli measured by changing the lengths of the beams of western redcedar and agathis, from 90 to 30 cm. Their Young's moduli were almost constant in the frequency range of 2 to 40 kHz.

In the steady-state vibration method, a small iron piece should be glued to the beam to excite its vibration. This piece must be regarded as an additional mass which affects the frequency when a beam is light. On the contrary, the tap method proposed does not require this additional piece.

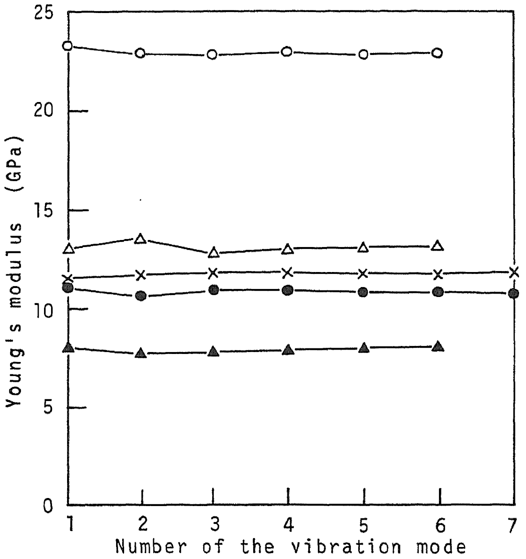

Fig. 2. Relationship between the Young's modulus and the number of the vibration mode of short beams.
Legend: ○, rosewood; △, buna; ×, keyaki; ●, shirakashi; ▲, hinoki.

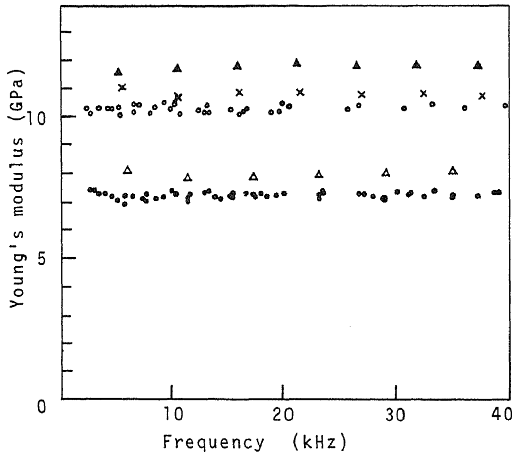

Fig. 3. Relationship between the Young's modulus and the resonance frequency of clear specimens.
Note: The Young's moduli of western redcedar and agathis were obtained by changing the lengths of the specimens.
Legend: ●, western redcedar; ○, agathis; ▲, keyaki; ×, shirakashi; △, hinoki.

3.2 Application to construction lumber of commercial size

The peaks of the power spectrum on 2 in.×4 in. dimension lumber were found until the 9th vibration mode in the best measuring case and at least until the 5th vibration mode.

As shown in Figure 4, the Young's modulus was

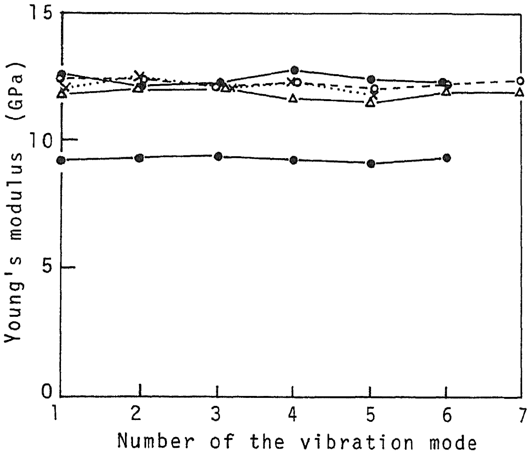

Fig. 4. Relationship between the Young's modulus and the number of the vibration mode for 2 in. × 4 in. dimension lumber.

almost constant against the number of the vibration mode. However, the change of the Young's modulus was slightly more than that of the clear short beams shown in Figure 2. This was probably because of knots and other defects in the commercial lumber.

The measurement of the commercial construction posts for the traditional Japanese house also was made at the lumber yard of a sawmill. A FM (frequency modulation) wireless microphone and the usual FM radio were used to detect and transfer the tap tone because of the ease of operation outdoors. The resonance frequencies were identified until the 7th vibration mode in the best case and at least until the 3rd vibration mode.

A beam 114 kg in weight and 20 cm × 20 cm × 6 m was hung horizontally by a hoist at the center of the beam which also was tapped, and clear resonance peaks until the 6th vibration mode which were adequate to calculate the Young's modulus were obtained.

The comparison between the Young's modulus by the longitudinal vibration and that by the flexural vibration is shown in Figure 5. The correlation coefficient of 0.963 illustrates the near perfect agreement between the two methods in spite of the great difference in the resonance frequencies. However, the

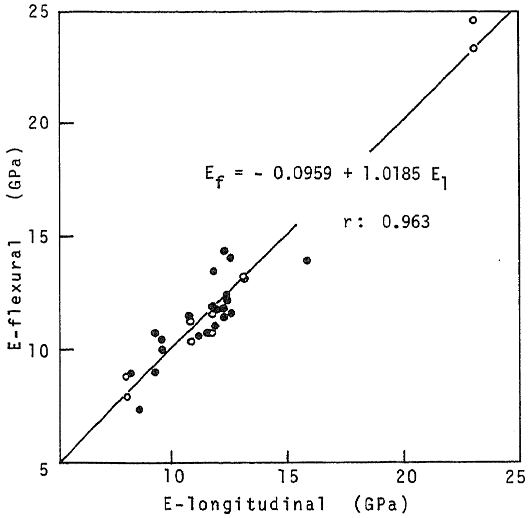

Fig. 5. Relationship between the Young's modulus measured by the transient longitudinal vibration and that by the flexural vibration.
Legend: ●, commercial construction lumber; ○, clear short beams.

dispersion of the data of commercial lumber is slightly greater than that of the clear short beams. This probably is due to the existence of such defects as knots in the commercial lumber and to the fact that the stress distribution which acts on these defects is not the same for these two methods.

Concerning the operation time of this system, the reading time of the tap-tone data by the FFT analyzer was 20 to 80 ms, and the FFT analysis time was about 200 ms. Therefore, an automated instantaneous measurement will become feasible if a microcomputer is connected to this measuring system.

4. CONCLUSIONS

The important conclusion of this work is that long lumber of commercial size can be vibrated sufficiently by a light tapping and that this tap method using a FFF spectrum analyzer is feasible not only for short beams but also for construction lumber of commercial size to obtain the Young's moduli. Another advantageous feature of this method is that the measurement of the Young's modulus in a wider frequency range up to 40 kHz can be made easily.

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