Dynamic Elastic Properties Measurement in Solid Materials by Impulse Excitation Technique

การวัดสมบัติยืดหยุ่นของวัสดุของแข็งโดยเทคนิคการกระตุ้นแบบการดล

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Abstract

The theory of elastic properties of a solid material was studied. The instrument based on an impulse excitation technique was designed and constructed to measure the elastic properties of solid materials (i.e. alumina, aluminum and copper). In addition, the program IEkku 1.0 has been built to calculate Young's modulus, shear modulus, and Poisson's ratio of the materials. The program was effectively used for the calculation of the elastic properties of the alumina materials, and is comparable to the standard program, the EMOD V1.7 program (J. W. Lemmens, Leuven, Belgium). The in-house instrument can be used for the frequency in the range of 0 kHz to 23 kHz, and it was successfully used to measure the elastic properties of aluminum and copper with the error of 1 - 3%.

บทคัดย่อ

ได้ศึกษาทฤษฎีของสมบัติการยืดหยุ่นของวัสดุของแข็งและทำการออกแบบสร้างเครื่องมือโดยใช้เทคนิคการกระตุ้นแบบการดล (impulse excitation technique) สำหรับวัดสมบัติการยืดหยุ่นของวัสดุของแข็งและได้สร้างโปรแกรม IEkku1.0 สำหรับ ใช้คำนวณหาค่ายังมอดุลัส เชียร์มอดุลัส และอัตราส่วนปัวซองส์ของวัสดุ โดยในการทดสอบวัสดุอลูมินาพบว่าโปรแกรม IEkku1.0 สามารถใช้งานได้อย่างมีประสิทธิภาพเทียบได้กับโปรแกรมมาตรฐาน IEkku1.0EMOD V1.7 (J.W. Lemmens, Leuven, Belgium) เครื่องมือวัดที่สร้างขึ้นสามารถใช้งานได้ในช่วงความถี่ 0 kHz ถึง 23 kHz และสามารถวัดสมบัติการยืดหยุ่นของอลูมิเนียมและทองแดงได้โดยมีค่าความคลาดเคลื่อน 1 - 3%

Key words : Elastic properties, impulse excitation technique, material characterization.

คำสำคัญ : สมบัติยืดหยุ่น เทคนิคการกระตุ้นแบบการดล การวิเคราะห์วัสดุ

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Introduction

The instrument in this study, based on the impulse excitation technique (ASTM C 1259-98, 1999), was constructed. In principle, the impulse excitation technique measures the fundamental resonant frequency of test specimens of suitable geometry (for example, rectangular or disc specimens) by exciting them mechanically by a single elastic strike with an impulse tool. A transducer (for example, contact accelerometer or non-contacting microphone) senses the resulting mechanical vibrations of the specimen and transforms them into electrical signals. Specimen supports, impulse locations, and signal-pick up points are selected to induce and measure specific modes of the transient vibrations. The signals are analyzed, and the fundamental resonant frequency is isolated and measured by a signal analyzer. A transducer is used to pick up mechanical vibration. The analogue signal from the vibration detector is first fed to a two-stage linear amplifier. A zero crossing detector marks off the signal periods. As soon as the peak detector senses that the incoming signal has started to decay, the successive period measurements commence. The instrument records all available periods and stores the results in the microprocessor memory for further analysis. When the incoming signal has died away, the processor selects the measurement corresponding to the preset and displays the result on the front panel. The test apparatus constructed and used in this study is shown in Fig.1. The appropriate fundamental resonant frequencies, dimensions, and density of the specimen are used to calculate the elastic properties of materials i.e. dynamic Young's modulus (E), dynamic shear modulus (G), and Poissons ratio (ν).

Methodology

In this study, we develop the program IEkku 1.0 to use for this purpose. In this study, two types of specimen shapes were used: rectangular bar (i.e. aluminum and copper) and disc (i.e. alumina).

The dynamic Young's modulus, E could be determined from the rectangular bar specimens, according to the following equation [2, 3]:

$$E = (0.94642 \rho f_f^2 L^4 / t^2) A_f \qquad (1)$$

where f_f is the fundamental resonant frequency (flexure mode) of a rectangular bar, L is the length, t is the thickness, ρ is the density of the specimen, and A_f is a correction factor to account for inertia effects. For a disc specimen, it could easily be excited into different modes, in particular the fundamental frequencies from flexural mode and torsional mode vibrations are of interest here as each of these two frequencies are used in the calculation of *E*, *G* and ν. The detail of how to get the vibration modes for a rectangular bar specimen and for a disc specimen can be obtained elsewhere (ASTM C 1259-98, 1999).

There are three main steps for the calculations of *E*, *G* and ν :

Step 1: Determine ν from the experimental values for flexural resonant frequency (f_1) and torsional resonant frequency (f_2). This is done by the use of the standard table [4] in which the value for n is interpolated from the table using the ratio of torsional resonant frequency to flexural resonant frequency (f_2/f_1) correlated with the ratio of the specimen thickness (t) to the specimen radius (R).

Step 2: Calculate two independent values for E (E_1 and E_2) using ν from step (1), f_1 and f_2.

Determine E as the average of the two independent calculations. Here E (E_1 and E_2) are expressed as follows:

$$E_1 = 37.6991 f_1^2 D^2 m\left(1 - v^2\right) / K_1^2 t^3,$$

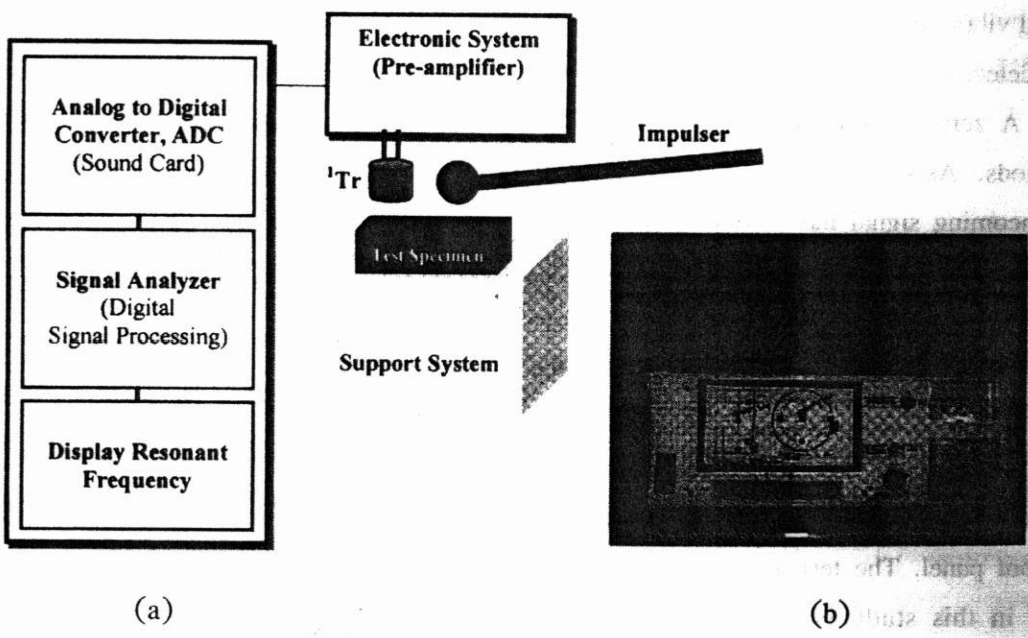
$$E_2 = 37.6991 f_1^2 D^2 m\left(1 - v^2\right) / K_2^2 t^3,$$

$$E = \left(E_1 + E_2\right) / 2,$$

where E is Young's modulus, E_1 flexural mode calculation of Young's modulus, E_2 torsional mode calculation of Young's modulus, f_1 flexural resonant frequency of the disc, f_2 torsional resonant frequency of the disc, D diameter of the disc, m mass of the disc, V Poisson's ratio, t the thickness of the disc and K_1, K_2 are the flexural geometric factor and torsional geometric factor, respectively (ASTM C1259-98).

Step 3: Calculate the value of G using V from step (1) and E from step (2): $G = E/2(1+V)$.

All of these procedures for the calculations of E, G and V for a rectangular and a disc specimen were included in the IEkku 1.0 program. To test the accuracy of the program, the data taken from the test on alumina are entered into the program and compared to the results obtained from the commercial software, the EMOD Version 1.7 program supplied by J. W. Lemmens, Leuven, Belgium. Fig. 2 shows the window display of the IEkku 1.0 program.



(a) (b)

Fig. 1 Block Diagram of Test Equipment (a) and the instrument for measure resonance frequency (b).
([1]Tr = transducer)

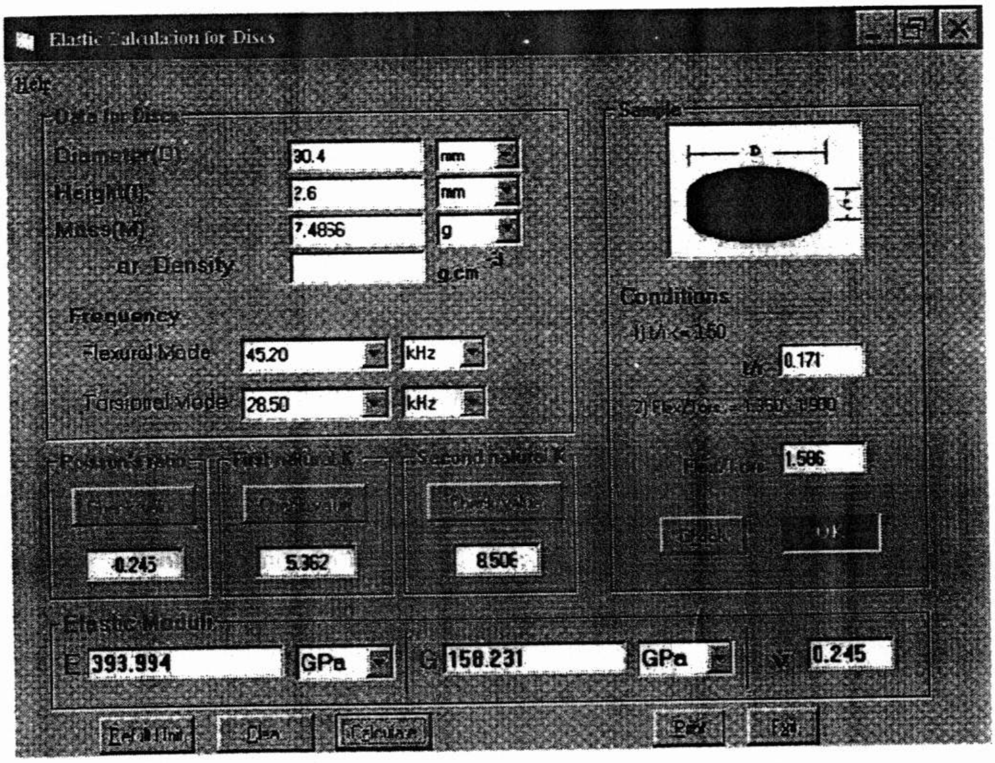


Fig. 2 The display of the IEkku 1.0 program.

Table 1 The elastic properties of aluminum and copper measured by the in-house impulse excitation system in association with the IEkku 1.0 program.

Material	Dimension (mm^3)	Mass (g)	f_1 (flexure) (kHz)	f_2 (torsion) (kHz)	E (GPa)	G (GPa)	ν
Aluminum 1	49.82x71.98x3.00	28.38	3.00	2.61	67.8	26.2	0.30
Aluminum 2	49.58x99.52x3.00	39.14	1.58	1.88	68.5	25.8	0.33
Aluminum 3	49.48x149.52x3.00	58.65	0.70	1.24	68.2	25.2	0.35
Copper 1	42.70x72.12x1.00	26.87	0.74	0.75	122.5	47.2	0.30
Copper 2	46.50x100.68x1.00	40.32	0.39	0.51	127.9	49.9	0.28
Copper 3	46.12x151.35x1.00	61.19	0.17	0.33	125.9	47.3	0.33

Results and discussion

By using alumina as a standard material, it was found that the calculation using the IEkku 1.0 program gives a good result and the measurement errors compared to that of using the EMOD V.1.7 for the Young's modulus, shear modulus and Poisson's ratio are 0.09%, 0.17%, and 0.69%, respectively. Therefore, the program was effectively used for the calculation of the elastic properties of the alumina materials. Young's modulus (*E*), shear modulus (*G*), and Poisson's ratio (*V*) of the aluminum and copper measured by the impulse excitation are shown in Table 1. The Young's modulus, shear modulus and Poisson's ratio of aluminum are respectively 68.2 ± 0.4, 25.7 ± 0.5, and 0.33 ± 0.03, while the Young's modulus, shear modulus and Poisson's ratio of copper are respectively 125.3 ± 2.6, 48.1 ± 0.5, and 0.30 ± 0.03. The measurement errors for *E* and *G*, compared to the standard values of both materials, are less than 3% but it is larger up to 12% for the error of *V*.

Conclusion

In this study, the instrument based on impulse excitation technique and the IEkku 1.0 program have been developed and successfully used to evaluate Young's modulus, shear modulus and Poisson's ratio of rectangular bar and disc specimens of solid materials such as aluminum and copper.

However, the instrument has the limit range in detecting the frequency of vibrations, and so far it can detect the frequency only in the range of 0 kHz to 23 kHz. Therefore, further work is needed to develop the system that can be used to detect a wider range of frequency, and this will increase the potential and efficiency of the instrument for measuring the elastic properties of various solid materials.

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References

ASTM: Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Impulse Excitation of Vibration. ASTM Designation C 1259-98, American Society for Testing and Materials, Philadelphia, (1999).

Spinner, S. J. 1960. Res. *National Bur. Stand.* 64A[2], 147-155.

Martincek, G. J. 1965. *Sounds Vibrat.* 2 [2], 116-127.

Pickett, G. 1945. *Proc. ASTM*, 45, 846-865.