Impact response measurement of a plastic container using a spherical-body drop-tester

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Abstract

In this work, the impact test between a spherical body and a plastic container using the adapted Levitation Mass Method (LMM) is carried out for investigating the dynamic behaviors of clear plastic container on the collision of a spherical body. The precise value of time-varying parameters are investigated by using simple Doppler effect occurred between the slightly different of beat frequency and rest frequency. The five experiments are carried out with our proposed method, it is confirmed to have good reproducibility.

Keywords: LMM, Impact testing, Dropped-weight test, Dynamic behaviors.

1. Introduction

The clear plastic products such as storage containers, packaged parts, etc. may be dropped during their use time. The dropping event can cause not only the cracking of container, but sometimes also cause the damage of inside product. This issue has become an important concern for the industry and logistics.

Some researchers reported methods for characterizing the behaviors of various kind of containers using the superior methods⁽¹⁻⁴⁾. We has proposed a method as known as the Levitation Mass Method (LMM)⁽⁵⁾. This method is very useful for characterizing the dynamic response of

tested materials such as human arm⁽⁶⁾, hard disk drive actuator arm⁽⁷⁾ and force transducer⁽⁸⁻¹⁰⁾. This method based on the fundamental theorem of the conservation of momentum in physics, but all necessities mechanics quantities are accurately obtained. This method has also been applied to impact force measurement of a spherical body dropping onto water surface⁽¹¹⁾.

In this work, the LMM method was adapted to investigate the dynamic behaviors of a plastic container on the collision of a spherical body. The time-varying parameters have been investigated precisely.

2. Experimental Procedure

2.1 Test specimen

A clear plastic container in rectangular-shaped with the dimension of 38.7 mm W × 67.7 mm L × 15.2 mm H was

Fig. 1. The photograph of plastic container.

used as the test specimen in this study.

2.2 Spherical body

A solid spherical-shaped tempered stainless steel SUS440 with the diameter of approximately 30.2 mm is employed as dropped object. A hole was implanted in order to employ a cube corner prism (CC) with an approximately diameter of 12.7 mm in center of gravity. The total mass of entire object included the CC is about 93.88 g. The photograph and illustrated for details are shown in Fig. 2 and Fig. 3.

2.3 Experimental setup

In order to characterize the dynamic impact behavior such as impact force, velocity and acceleration, free-fall drop tests were conducted using the equipment that consist of the following items as seen in Fig. 4.

The spherical body was lifted and suspended at the top position with a certain drop height of 5.87 cm using a hollow-circular electromagnet. By manually turning on/off the magnet, the spherical body was launched and collided to the test specimen.

The two orthogonal beams of light generated from Zeeman-type two-frequency He-Ne laser were incident on polarizing beam splitter (PBS). After the light propagation in the Michelson interferometer, the signal and reference beam are passed through a polarizer (a Glan-Thompson prism at 45° to the polarization of the beams) and interfered.

Fig. 2. The photograph of the spherical body.

Fig. 3. The details of the spherical body.

The interference beams were incident on the photo detector with slightly different in frequency and resulted in beat frequency, f_{beat} . When the drop object was standstill at the top position, the beat frequency, f_{beat} , and the rest frequency, f_{rest} , is the same frequency, which was approximately 3 MHz.

In addition, a digitizer (NI PCI-5105, National Instruments Corp., USA) is used to monitor the beat and the rest signal with sampling rate of 30 M samples per second and 12-bits resolution. Therefore, the 5 M data were obtained during the sampling interval of 0.167 second in each channel. The digitizer is initiated by a trigger signal from a digital to analogue converter, which is triggered by a signal generated by a combination of a laser diode and a photodiode.

To verify the repeatability and stability of the results, repetitive tests were conducted for five times on the same plastic container.

3. Results and Discussions

The analytical data processing started with the measured values of f_{beat} and f_{rest} as shown in Fig. 5. The ZFM: Zero-Crossing Fitting Method⁽¹²⁾ which is proposed by one of authors was deployed to estimate the frequencies, f_{rest} and f_{beat} .

Figure 6 shows following data analytical process for obtaining to determine the velocity, v , the displacement, x , acceleration, a , and impact force, F . The velocity, v , can be obtained by using the following relation:

Fig. 4. Experimental setup. (Code: PBS = Polarizing beam splitter, CC = Corner cube prism, GTP = Glan-Thompson prism, PD = Photo diode, LD = Laser diode, ADC = Analog-to-digital Converter, DAC = Digital-to-analog converter.)

Fig. 5. The value of f_{beat} and f_{rest} from the 1st experiment.

$$v = \lambda_{air} \times \frac{f_{Doppler}}{2} \quad (1)$$

where λ_{air} is the wavelength of signal beam and is equal to 632.8 nm. By integrating and differentiating the velocity, the displacement and acceleration of the spherical body are obtained. Finally, by calculating the product of the acceleration and mass of the spherical body, the force acting on the spherical body is obtained. This force is the resultant force of gravity and impact force.

Figure. 7 shows the time-varying force of the 1st experiment. It is found that the impact force F exerted on the plastic container with maximum value of 55 N (first peak) with the displacement x of 0.0017 m can cause the cracking on the plastic container and decreased the magnitude because the ball lost its kinetic energy in term of sound and heat energy.

Figure 8 shows the variation of force against the position. The changes in the inclines of the plot before and after the crack generation indicates the changes of spring constant of the plastic container.

Figure 9 shows the all experimental results for the comparison. As shown in Fig. 9 (a), the plot shape of 1st experiment, 2nd experiment were different. However, after 3rd experiment, the shapes were almost the same. This result may show that at the 1st experiment, a crack was generated. At the second experiment, the crack might become larger. After 3rd experiment, the size of crack might not change.

Compared to conventional drop ball tester, this method is possible to measure not only the force acting on the test specimen but also the position and velocity of the dropped ball. These additional information will help analysis of the dynamic behavior of the test specimen on the collision.

(a) Velocity.

(b) Displacement.

(c) Acceleration.

(D) Force.

Fig. 6. Data processing procedure.

Fig. 7. The time-varying force of the 1st experiment.

Fig. 8. The variation of force against the position.

Conclusions

In this work, the adapted LMM method was used to characterize the dynamic response of plastic container on the collision of a spherical body. The time-varying parameters such as velocity, position, acceleration and impact force have been obtained throughout the Doppler shift in wavelength between the beat and rest frequencies. With the maximum impact force about 55 N can cause the damage of test specimen in the 1st experiment. In order to verify the reliability of this method, the five experiments have been carried out. The results showed that the time-varying parameters with high accuracy were obtained by the proposed method and this proposed method has good reproducibility.

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(a) The time-varying forces.

(b) The variation of force against the position.

Fig. 9. The plots of impact force against the position for all five experiment.

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