Measurement of Transient Dynamic Response of Circuit Boards of a Handheld Device During Drop Using 3D Digital Image Correlation

S. B. Park
e-mail: sbpark@binghamton.edu

Chirag Shah

Jae B. Kwak

Changsoo Jang

Soonwan Chung

James M. Pitarresi

Department of Mechanical Engineering,
State University of New York at Binghamton,
Binghamton, NY 13902

In this work, a new experimental methodology for analyzing the drop impact response is assessed using a pair of high-speed digital cameras and 3D digital image correlation software. Two different test boards are subjected to Joint Electron Device Engineering Council (JEDEC) standard free-fall impact conditions of half-sine pulse of 1500 G in magnitude and 0.5 ms in duration. The drop is monitored using a pair of synchronized high-speed cameras at a rate of up to 15,000 frames per second. The acquired images are subsequently analyzed to give full-field dynamic deformation, shape, and strain over the entire board during and after impact. To validate this new methodology for analyzing the impact response, the in-plane strain as well as the out-of-plane acceleration at selected locations were measured simultaneously during the drop using strain gauge and accelerometers and were compared with those obtained using high-speed cameras and 3D digital image correlation presented in this paper. Comparison reveals excellent correlation of the transient behavior of the board during impact and confirms the feasibility of using the full-field measurement technique used in this study.
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1 Introduction

With the ever-growing market for handheld electronic products, there are strong demands for reliability testing of handheld devices [1,2] or circuit boards [3,4] under drop impact conditions. The impact or shock response of components and boards has been investigated and quantified to improve their service life [5–8]. To standardize the test methodology and provide a reproducible assessment of the drop test performance, JEDEC [9] suggested test standards related to drop and shock tests. These standards provide a common ground for the assessment of component performance for impact loading. Currently, most of drop/impact tests have been performed based on JEDEC standards, and numerical methodologies have been developed to predict failure mode and impact life. Most works [1–3] have focused on the correlation between test and simulation to verify that numerical models are reliable and suitable to be used in drop/impact simulations.

Strain gauges have traditionally been used in drop tests to infer the deformation at a certain location of interest in virtue of their low cost, simplicity in use, and versatile application. However, there are several limitations in the use of strain gauges. First, the strain information is averaged over the gauge length and can be obtained only at the location where the strain gauge is mounted. Second, the gauge is potentially subjected to temperature, humidity, and other conditions that might impede its functionality. Third, due to potentially large deformations during board flexure, there is a possibility that the gauge might undergo some permanent deformation. Therefore, the significance of this work lies in a novel approach of noncontact and full-field optical 3D digital image correlation (DIC) technique [10,11] in conjunction with high-speed cameras [12]. From this new methodology, the full-field transient dynamic response of a test vehicle can be mapped when it is subjected to impact loads.

In this study, JEDEC standard conditions of half-sine input pulse of 1500 G in magnitude and 0.5 ms in duration are used. Two kinds of test boards provided by manufacturers are used as test vehicles. The in-plane strains calculated by the DIC are compared with the strain recorded by strain gauges simultaneously during the drop. Additionally, the out-of-plane accelerations calculated by double differentiating out–of-plane displacement from 3D DIC are compared with the accelerations recorded by the accelerometers mounted on board.

2 Experimental Setup and Procedure

2.1 Specimen Preparation and Calibration. DIC is a full-field optical measurement technique by which both the in-plane and out-of-plane deformations can be computed by tracing the movement of speckles on the target object. In order to obtain feasible speckles, a random high contrast dot pattern was applied to the top surface (component side) of the board by using spray paint. The cameras were calibrated using GOM® calibration panels for each field of view (FOV). The pictures of the panel were sequentially captured at different distances and orientations. Then, a photogrammetry process known as bundle adjustment is used to establish the precise relationship between the two cameras. For accurate camera calibration, the size of dots on the specimen surface should be inversely proportional to the desired camera resolution. The high speed cameras used in this study has maximum imaging speed of 1200 frames per second in 1024×1024 pixels. The resolution is traded off for higher frame rates.

2.2 Drop Tester. A shock test system, Lansmont® M23, is equipped with an electric hoist lifting system to permit accurate and easy drop height changes and variable drop heights. The shock table incorporates pneumatic rebound brakes that prevent multiple impacts and serve as an important built-in safety feature. The heavy steel seismic base has been designed to absorb impacts of up to 5000 G of acceleration and allow minimal shock to be transmitted to the surroundings. It is supported by four pneumatic cylinders, which position the base for the table to impact squarely. A voltage-type accelerometer with a sensitivity of 0.432 mV/g was rigidly bolted onto the base plate of the shock table to measure the input shock pulse to the system. For dynamic validation of high-speed measurement, the bottom side of the board was instrumented with a strain gauge (9 mm offset from the center) and two charge-type accelerometers weighing about 0.2 g with a sensitivity of 0.58 pC/g, as shown in Fig. 1. One accelerometer was installed at the center of the board while the other was on a corner of the board near the standoff screw. The accelerometers measure the out-of-plane accelerations, and the strain gauge measures the in-plane strain during the impact sessions. The filtered output from the signal conditioners was recorded and digitized on the data acquisition system at about 83 kHz.

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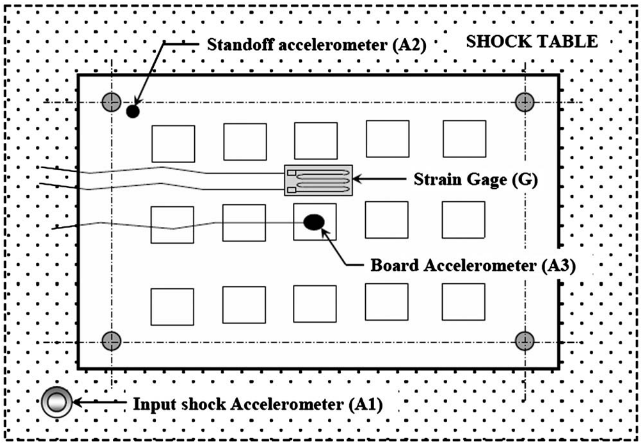

Fig. 1 The bottom of the board showing the position of the accelerometers and the strain gauge

2.3 High-Speed Measurement. Figure 2 shows a schematic of the experimental setup for high-speed measurement. Two test boards of different dimensions were used to demonstrate the versatility of the measurement technique, viz., test board A (132×77 mm^2, JEDEC standard) and test board B (75×40 mm^2). Nikon® f2.8 28 mm lenses were used in conjunction with the Phantom -v7.0® cameras for image capture. The powerful 650 W halogen lighting allows the cameras for a minimum exposure of 10 ms and up to 100,000 frames per second. In this experiment, an exposure of 56 μs and a maximum capture frequency of up to 15,000 frames per second were used. A pair of cameras was well synchronized frame-by-frame up to a 2% jitter by locking them to an IRIG® timer. To avoid the overheating of the test surface due to prolonged exposure to high-intensity lighting, cooling fans were used to continuously cool the surface until no residual strain is visible in the strain gauge conditioner. The cameras were triggered just before the table impacted the strike surface. The full-field images acquired from both cameras were analyzed to reveal the 3D deformation, shape, and strain over the board surface.

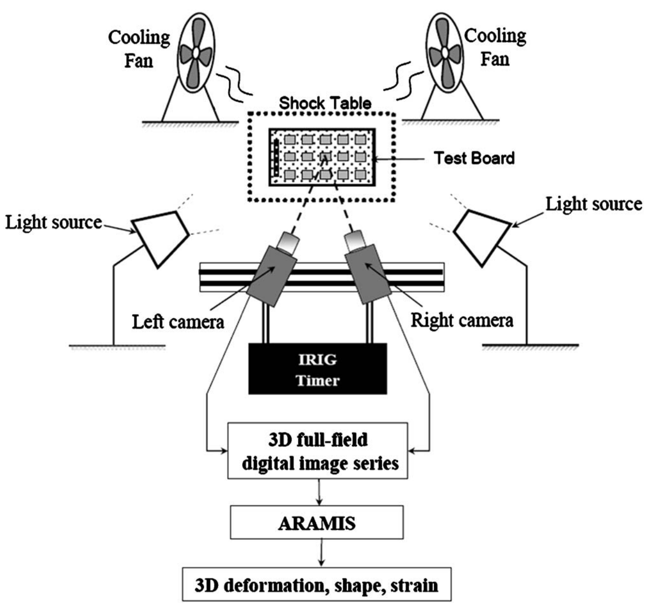

Fig. 2 Schematic of high speed measurement setup

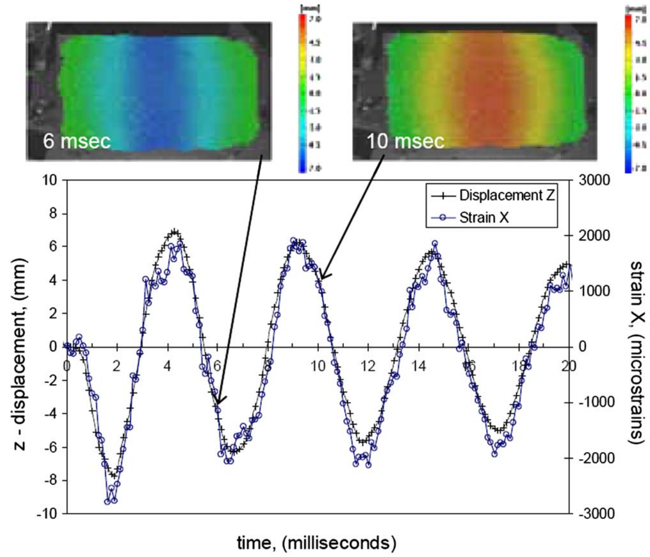

Fig. 3 Time-history of the out-of-plane displacement at the board center and in-plane strain at the strain gauge mounting location on test board A

3 Experimental Results and Discussions

The image correlation software checks and eliminates any rigid body motion by calculating the relative changes in pixel coordinates over the entire field of view. In this study, the points near the standoff screw on the test board were chosen as references in calculating out-of-plane displacements. Figure 3 shows the out-of-plane displacement versus time at the center of test board A, as it is subjected to the free-fall impact. It also shows the time-history of the longitudinal strain at the strain gauge location together with typical processed images at particular moments. At 8000 frames per second with 448×252 pixel resolution, about 40 frames were captured per fluctuation cycle for test board A. This rate may not be sufficient for other cases. For instance, the smaller test board B is naturally stiffer and vibrates with much higher frequency. Therefore, much higher the frame rate (15,000 frames per second), the shorter exposure time (56 μs) and the coarser resolution (320×188 pixels) were used to capture the impact response of test board B. Figure 4 shows the time-history of the out-of-plane displacement at the board center of the test board B along with processed images. It demonstrates that the reduced pixel resolution is still sufficient to attain detailed deformation fields over the test board.

3.1 Validation. Figure 5 shows the comparison of longitudinal strain acquired by the high-speed cameras and by conventional resistance wire strain gauge at the same location for test board A. An appropriate change in sign would be required to make the strain gauge data, which is taken at the bottom surface, consistent with that of high-speed DIC measurement, which is taken at the top surface of test board. The good agreement between two data, as shown in Fig. 5, confirms that in-plane strain from high-speed cameras well represents the actual deformation induced by drop impact. Additional validation was attempted by comparing the acceleration response calculated by both methods, as shown in Fig. 6. The out-of-plane displacement data obtained from high-speed cameras were differentiated twice to obtain the relative out-of-plane accelerations and were compared with the accelerations recorded by the accelerometer mounted at that location. It was calculated by subtracting the acceleration at standoff screw (A2 in Fig. 2) from the acceleration at the board center (A3 in Fig. 2). It can be seen that the board response is composed of high frequency waves (of frequency several thousand hertz) modulated by

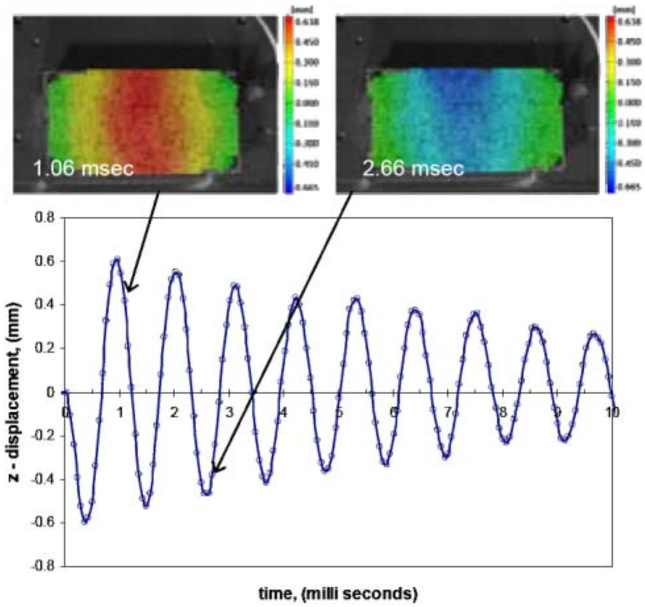

Fig. 4 Time-history of the out-of-plane displacement at the center of test board B

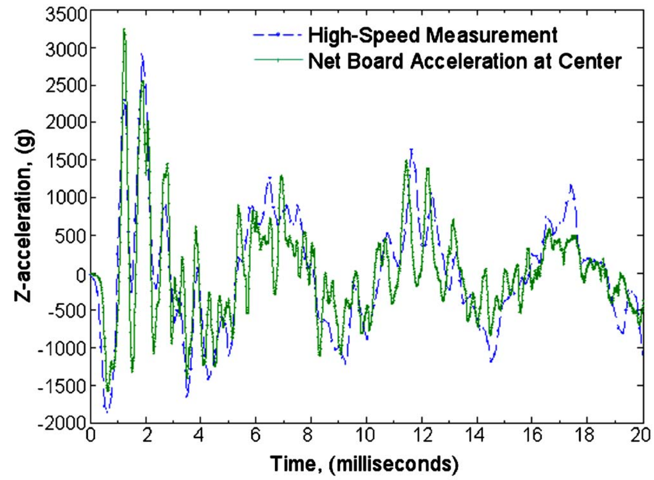

Fig. 6 Test validation of high-speed measurement with accelerometer time history at the center of board A

low frequency primary carriers having a frequency of about 200 Hz (i.e., 5 ms time period). The two measurements agree well with each other in terms of the primary carrier frequency although the peak accelerations are different. In addition, this primary frequency is in good agreement with the frequency of the plots for warpage calculated by the DIC (Fig. 3). The difference in the peak values of accelerations calculated by both measurements can be attributed to the different sampling rates. The sampling rate (83 kHz) of the drop tester is at least five times faster than the highest frame rate for DIC measurement (8 kHz and 15 kHz).

4 Conclusions

A novel full-field optical technique for measuring the dynamic response of test vehicle subjected to drop shock was developed and validated by using high-speed cameras and 3D digital image correlation. Two test boards of different dimensions were used to demonstrate the capability and versatility of this technique. Dynamic displacement data such as displacements, strains, and accelerations obtained from this methodology suggested were in good agreement with that obtained in the lab using conventional strain gauges and accelerometers. Not only does this technique help in better understanding the dynamics of the problem but also gives an accurate quantification of the impact behavior of the test vehicle at hand. This methodology will be an invaluable tool in verifying and iterating the subsequent finite element models to be used for optimal design under impact loading.

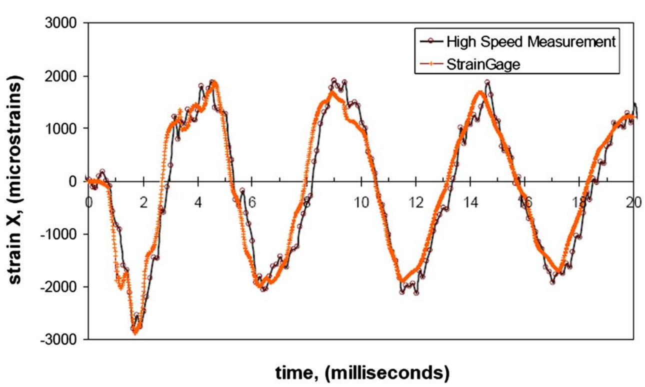

Fig. 5 Test validation of high-speed DIC measurement compared with strain gauge for test board A

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