Incorporating a Research Project in an Undergraduate Level Engineering Course

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Abstract

This paper presents an example of incorporating a research project in the undergraduate system dynamics course. The research topic is in the area of drop impact reliability for the handheld electronic products. Portable electronic devices are prone to accidental drops during their service life. Board level solder joint reliability during drop impact is a great concern to electronic product manufacturers. The drop test has become a key qualification test for portable electronic products in recent years. However, actual drop test is very expensive and time-consuming. It requires much manpower in measurement and failure analysis. An alternative approach is to develop analytical dynamic models and to perform numerical simulations. The drop impact test can be simplified as a single degree of freedom dynamic system. The project of modeling and simulation for the drop impact test is assigned in the class. In the paper, the description, implementation and assessment of the teaching are presented. The results of implementation of the projects were very promising.

Introduction

System dynamics represent an important subject in mechanical engineering. This paper describes a practice to integrate the state-of-art research topics into the undergraduate system dynamics course. The project provide the missing link between the theoretical concepts and the real engineering world, thus helping the students to capture the essential aspects of the problems in a mechanical model, make reasonable simplifying assumptions, and reduce this model into solvable problems such as single degree of freedom free and forced vibrations [1].

The research topic used here is related to the study on reliability performance of electronic products during drop impact. This is a great concern to semiconductor and electronic product manufacturers, especially for portable devices such as mobile phones and PDAs [2-10]. It is not uncommon for those portable electronic products to be accidentally dropped onto the ground. Vulnerable elements inside such products may experience very high accelerations and dynamic stresses. This ultimately causes failures in solder joints, intermetallic layers at solder-pad interface, or board via cracking. The impacts and shocks thus can lead to the failure of electronic packages and the malfunction of the products. Board level drop test has become a key qualification test for portable electronic products in recent years. JEDEC standard [9] provides suitable guidelines for conducting qualification tests for electronic components and sub-assemblies subjected to mechanical shock environments. However, the effects of peak acceleration, duration, and shape of impact pulse are not emphasized there, which should be key variables that affect the solder joint reliability during drop impact. Actual drop test is very expensive and time-consuming. It requires much manpower in measurement and failure analysis. It is almost impossible to study the effect of impact pulse by actual testing due to the difficulties to achieve various kinds of required impact pulses. An alternative approach is to develop analytical dynamic models and to perform numerical simulations. Although a full-scale finite element analysis with complicated geometry can be carried out, it is very time-consuming, and the problem can be so complicated that it is difficult to capture some most important affected factors in engineering design. Therefore, it is necessary to develop an efficient analytical analysis for the problem. Board level drop test can be simplified and analyzed as a one degree of freedom dynamic system. The project of modeling and simulation for the drop impact test is assigned in the system dynamics course. It is required to find both analytical and numerical solutions for the different input signals.

In the paper, the board level drop impact test is introduced first. Simplified model and input pulse are presented then. Assessment and conclusion are given at the end of the paper.

Board Level Drop Impact Test Method

JEDEC provided the standardized board level drop test method for manufactures. It recommends mounting 15 package components on the test board in 3 rows of 5 components each. The test board is mounted on a base plate by 4 screws at the corners. This base plate is then mounted on a drop table. The drop table, guided by guide rods, is allowed to strike on a rigid base from some specified height. Figure 1 is the typical drop apparatus and mounting scheme [9].

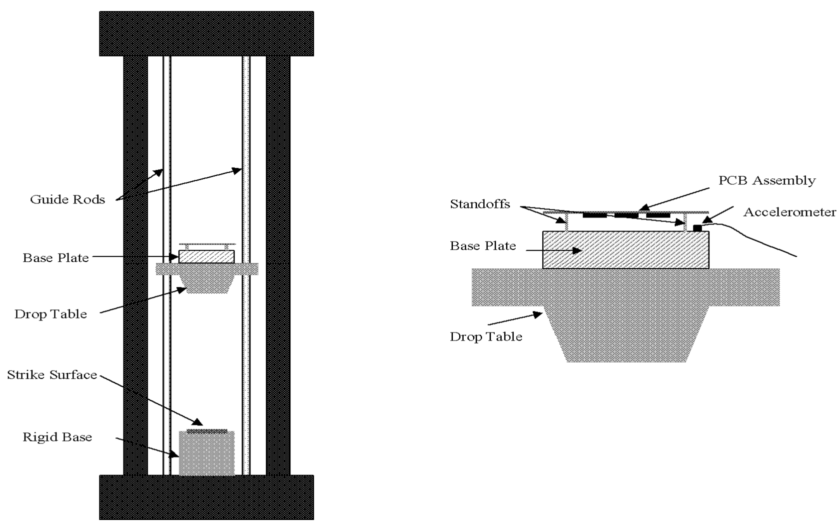

Figure 1. Typical drop apparatus and mounting scheme [9]

Dynamics of Board Level Drop Impact Test

Simplified Model

Figure 2a schematically illustrates a board level drop test. In the experimental set-up, this prescribed acceleration pulse is achieved by manipulating the fall height and the stiffness of the shock pad. An understanding of the mechanics of this event will be useful for the conduct of the experiment [4]. The base structure and the connectors are typically made of metal whose longitudinal stiffness is much higher than the flexural stiffness of the PCB. Thus the PCB board in the drop test can be simplified as a single DOF spring-mass system, as shown in Figure 2b. The acceleration pulse will therefore transmit to the PCB through the base and the connectors with little distortion. As such, the analysis of a board level drop impact may be reduced to modeling the PCB alone subjected to the acceleration pulse applied at its points of mounting to the connectors.

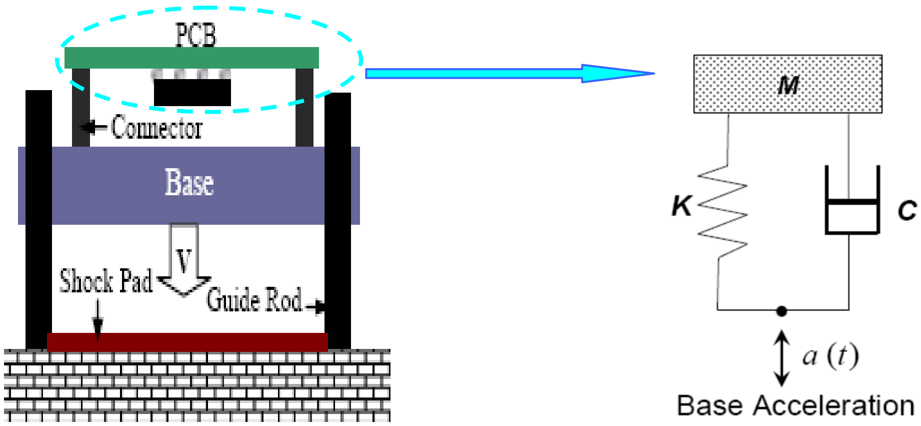

Figure 2. (a) Schematic board level drop test [4]; (b) Simplified single DOF model [5]

The equation of motion for the PCB board is

$$M\ddot{x}(t) + B\dot{x}(t) + Kx(t) = f(t) \tag{1}$$

where M is the mass, B is the damping coefficient, and K is the spring constant of the test PCB board, x(t) is the displacement of the test board of the system, and f(t) is the applied acceleration pulse. As the first step analysis, the damping effect is neglected.

The acceleration pulse can be three cases, as shown in Figure 3. A half-sine forcing function input profile is usually used to simulate the end-user impact conditions, and the trapezoidal input profile simulates the shipping shock environment. Rectangular pulse impact is the simplification and approximation of trapezoidal input which can be used to find the closed-formed solution easily.

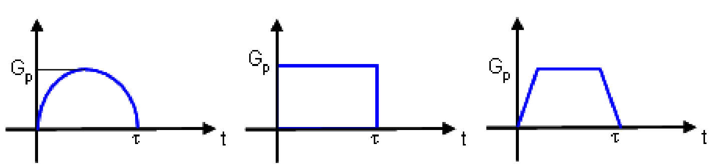

Figure 3. Acceleration pulse: (a) sine curve, (b) rectangular curve, (c) trapezoid curve

For the rectangular pulse input forced vibration with zero initial conditions, as shown in Fig. 3(b),

$$f(t) = \begin{cases} G_p, & 0 \le t \le \tau \\ 0, & t > \tau \end{cases} \tag{2}$$

where G_p and τ are amplitude and duration of the rectangle pulse curve. For the half-sine input forced vibration, as shown in Fig. 3(a),

$$f(t) = \begin{cases} G_p \sin(\frac{\pi t}{\tau}), & 0 \le t \le \tau \\ 0, & t > \tau \end{cases} \tag{3}$$

where G_p and τ are amplitude and duration of the half-sine curve.

Analytical Solution for the Rectangle Pulse Input

With the rectangle pulse input of magnitude G_p and duration τ, the equations and initial conditions can be expressed piecewise by Eqs. (4) and (5).

$$\begin{cases} m\ddot{x} + kx = G_p \\ x(0) = \dot{x}(0) = 0 \end{cases} \quad \text{when } t \le \tau \tag{4}$$

and

$$\begin{cases} m\ddot{x} + kx = 0 \\ \text{ICs}: x(\tau) \text{ and } \dot{x}(\tau) \text{ obtained from Eq (6)} \end{cases} \quad \text{when } t > \tau \tag{5}$$

Define the resonant frequency as $\omega_n = \sqrt{k/m}$. When $t \le \tau$, the solution of Eq. (4) is

$$x(t) = \frac{G_p}{m\omega_n^2}\left(1 - \cos\omega_n t\right), \text{ when } t \le \tau \tag{6}$$

Thus,

$$\dot{x}(t) = \frac{G_p}{m\omega_n}\sin(\omega_n t) \tag{7}$$

Eqs. (6) and (7) are results of the Eq. (4), which are needed for the initial conditions in Eq. (5).

Therefore, Eq. (5) can be re-written as

$$\begin{cases} m\ddot{x} + kx = 0 \\ x(\tau) = \frac{G_p}{m\omega_n^2}\left(1 - \cos\omega_n \tau\right) \\ \dot{x}(\tau) = \frac{G_p}{m\omega_n}\sin(\omega_n \tau) \end{cases} \quad \text{when } t > \tau \tag{8}$$

In order to solve Eq. (8), we assume $t_1 = t - \tau$, and then Eq. (8) becomes

$$\begin{cases} m\ddot{x}(t_1) + kx(t_1) = 0, \quad t_1 = t - \tau \\ x(0) = \dfrac{G_p}{m\omega_n^2}\left(1 - \cos(\omega_n \tau)\right) \\ \dot{x}(0) = \dfrac{G_p}{m\omega_n}\sin(\omega_n \tau) \end{cases} . \tag{9}$$

By solving Eq. (9), we have

$$x(t-\tau) = \frac{G_p}{m\omega_n^2}\left[\left(\cos\omega_n(t-\tau)\right) - \cos\omega_n t\right] \text{, when } t > \tau . \tag{10}$$

The displacement response of tested board subjected to a rectangular pulse can be expressed by Eqs (6) and (10).

Analytical Solution for the Rectangle Pulse Input

With the half-sine input of magnitude G_p and duration τ, the equations and initial conditions can be expressed piecewise by Eqs. (11) and (12).

$$\begin{cases} m\ddot{x} + kx = G_p \sin(\pi t / \tau) \\ x(0) = \dot{x}(0) = 0 \end{cases} \quad \text{when } t \le \tau \tag{11}$$

and

$$\begin{cases} m\ddot{x} + kx = 0 \\ \text{ICs } x(\tau), \dot{x}(\tau) \text{ obtained from Eq (11)} \end{cases} \quad \text{when } t > \tau . \tag{12}$$

Similar to finding the closed-form solution for the rectangular pulse input, the displacement response of tested board subjected to a half-sine pulse can be expressed by the following two equations, i.e., Eqs (13) and (14).

$$x(t) = \frac{G_p}{m}\frac{1}{\omega_n^2 - (\pi/\tau)^2}\left[\sin\left(\frac{\pi t}{\tau}\right) - \frac{\pi}{\tau\omega_n}\sin(\omega_n t)\right], \text{ when } t \le \tau \tag{13}$$

and

$$x(t-\tau) = -\frac{G_p \pi}{m\tau\omega_n\left(\omega_n^2 - (\pi/\tau)^2\right)}\left\{\sin(\omega_n t) + \sin[\omega_n(t-\tau)]\right\}, \text{ when } t > \tau \tag{14}$$

Numerical Simulation

A MATLAB/SIMULINK model can be developed to simulate the system's dynamic response. The numerical model can facilitate the parameter study. Using the tool, the relationship between input and output can be obtained and visualized easily and quickly with selected system parameters. The block diagram and the corresponding SIMULINK models are shown in Fig. 4.

The input impact pulses are generated in MATLAB workspace for three different situations before the execution of the SIMULINK model. Both displace and acceleration can be displayed at the same time. It is difficult to find the trapezoid pulse input theoretically, however, the numerical solution can be easily obtained by the A MATLAB/SIMULINK model.

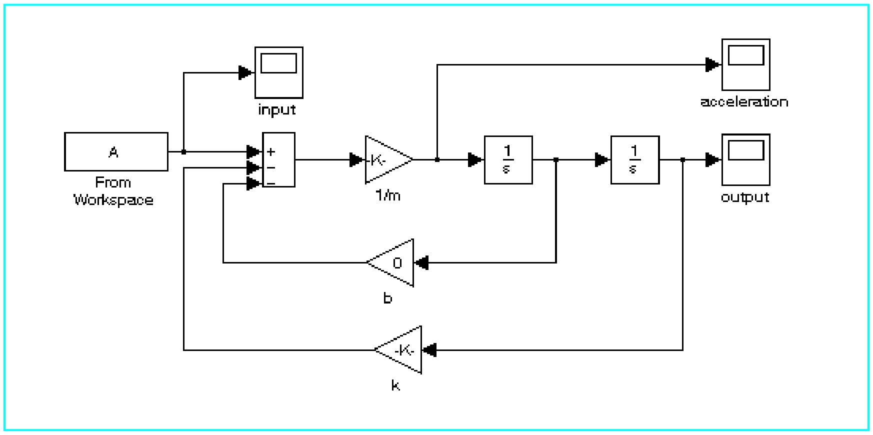

Figure 4. Block diagram and SIMULINK model

Here we use the example of half-sine input. Carefully choose the design parameters; we have the mass M as 25 gram and K as 40 N/mm. The input half-sine function is defined by JEDEC standard as peak acceleration A0 is 1500Gs and time duration τ is 0.5 milliseconds. With all the parameters defined in the MATLAB/SIMULINK model, the input pulse and system dynamic response for the output displacement and acceleration are obtained in Figures 5-7. The output displacement is oscillating up and down with the same peak value.

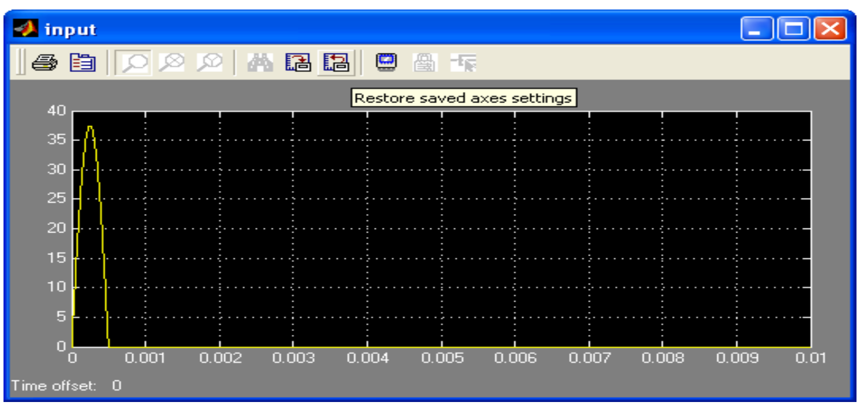

Figure 5. Input excitation to the test board with standard input. The horizontal axis is time (seconds) and the vertical axis is the input excitation corresponding to Gs.

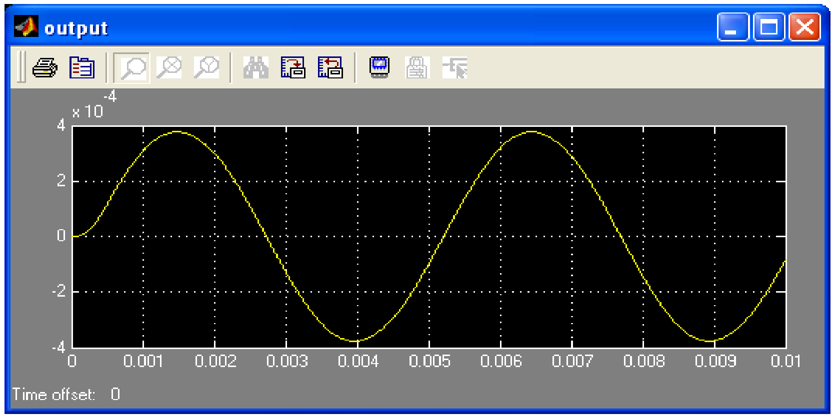

Figure 6. Output displacement of the test board with standard input. The horizontal axis is time (seconds) and the vertical axis is the displacement (m).

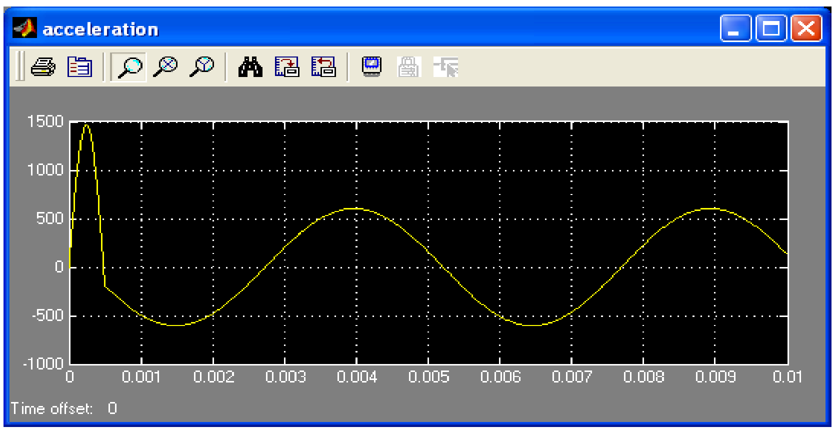

Figure 7. System response of acceleration of the JEDEC test board with standard input. The horizontal axis is time (seconds) and the vertical axis is the acceleration (Gs).

Students' Project Assignments

Board level drop test can be simplified as a one-degree-of-freedom dynamic system. The students are assigned the project when they are in the process of learning single-degree-of-freedom system. Both theoretical and numerical solutions are required to find the displacement and acceleration of the drop test board.

In specific, the students are required to finish the following tasks:

1. Simplify the standard JEDEC board level drop test system as a single-degree-of-freedom system, and derive the simplified system's equations of motion.
2. Derive the closed-form time response of the system with piecewise half-sine excitation or rectangular excitation.
3. Develop a MATKAB/SIMULINK model to simulate the displacement response and acceleration response of the test board numerically for three different inputs.

Assessment

The project was assigned in teaching the course of system dynamics for the mechanical engineering students in spring 2008. Students' satisfaction survey on the project assignment was performed. Students answered questions on a Likert [12] scale of 1 (truly inadequate) to 7 (truly outstanding). The result is shown in Table 1. While there is no hard evidence yet, the results of implementation of the project in spring 2008 were very promising. The students indicated that they felt that doing the projects helped them better understand course concepts. The effect of the real world projects improved student satisfaction and student examination performance in the course. Full formal assessment and evaluation for the project are planning to be conducted in spring 2009.

Table 1: Student satisfaction survey

Student Number	Average	Standard Deviation
35	5.8	1.2

Conclusion

This project shows a mechanical application in the electronic industries. The project also demonstrates the direct application of mechanical vibrations and system dynamics to real world problems. This motivates and retains the students' interests in learning the subject, and inspires their recognition of the need of life-long learning. The integration of the research project has been successfully implemented in a course in system dynamics. The results of implementation of the projects were very promising. The projects introduced here can also apply to the teaching of the course of engineering vibration as well.

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