Journal of Solid and Fluid Mechanics (JSFM), 13, (1):1-3, 2023

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/JSFM.2023.12482.3675

Manufacturing Engineering of Iran

Analytical investigation of the leg geometric characteristics effect of the electronic board on the shock transmission caused by satellite separation

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Received: 12/08/2022 Revised: 03/14/2023 Accepted: 05/01/2023

Abstract

The satellite system is subjected to shock during launch and separation, which causes damage to various parts, including the electronic system.. In this article, the electronic board of the satellite guidance system has been analytically examined. This board is located on 5 legs that are connected to the body. The purpose of this study is to design the legs so that the least amount of shock is introduced to the electronic board. The electronic board is assumed to be a plate. Effective parameters in shock transmission, including geometrical parameters and the leg angle with the horizon surface, have been studied. The influence of the leg angle with the horizontal surface on the stiffness of the system has been investigated using analytical relations. Finite element simulation has been used to validate the equivalent stiffness. The results of this study show that changing the leg angle causes the transmissibility of acceleration to change according to the excitation frequency. Acceleration transmissibility depends on the ratio ω/ω_n. For this reason, different parameters should be selected according to the excitation frequency range. If different parameters are not selected properly, the output acceleration will be higher than the input acceleration.

Keywords: Electronic board, leg, shock, satellite

1. Introduction

The correct functioning of electronic systems is very important in the functioning of the satellite guidance system. The satellite is subjected to shock during launch and separation, which causes damage to various parts, including the electronic system. The shock created can damage its electronic systems and disrupt the functioning of these systems. Researchers have conducted research on reducing the effects of shock on satellite systems.

Park et al. [1] analyzed the dynamic characteristics and shock response of vibration isolation systems that support discs. Fulcher et al. [2] investigated the behavior of the beam mechanism with a bend to isolate the vibration and reduce the shock effect. Tapia and Ledezma[3] investigated the vibration and shock isolation performance of several cable isolators under axial loading. They also studied the shock response of the isolators when exposed to pulses of different durations. Ismail and Ferguson [4] presented a new shock isolation strategy for the base excitation system by introducing a two-degree-of-freedom model with passive friction. They compared the performance of the model in terms of maximum displacement and acceleration responses during shock input applications. Cao et al. [5], considering the advantages of superior damping properties of metal rubber, designed its structures for vibration absorbers. They comprehensively analyzed the dynamic behaviors of the integrated system. Wu et al. [6] investigated the mechanical behavior of entangled metal wire materials under quasi-static and impact loading and analyzed the impact energy absorption mechanism. park et al. [7] proposed a new design of sandwich plate insert for impact attenuation and investigated its application in a space structure. Their study showed that the shock absorber insert provided by them saves space and provides dynamic stability. To solve the problems of shock environment and shock isolation, Hui et al. [8] presented a shock detection method that can quantitatively distinguish between shock and forced vibration mode.

In this paper, an electronic board that is connected to the body with 5 legs and is subjected to mechanical shock is analyzed analytically. The purpose of this study is to design and analyze the bases in such a way that the electronic board has the lowest amount of acceleration under the shock from the body. To achieve the stated goal, parameters such as the geometric dimensions of the leg and the leg angle with the horizontal surface have been selected as variables.

2. Modeling

In the modeling, the electronic board is assumed to be rigid. The legs for connecting the electronic board to the body of the satellite are considered symmetrical. A circular electronic board is connected to the body using 5 legs that have an angle α with the horizontal surface. To investigate the behavior of the system under shock, the system is modeled as an equivalent mass and spring, where each leg is assumed to be a spring. Considering that the electronic board has 5 parallel legs (Figure 1), 5 parallel springs are assumed in the modeling.

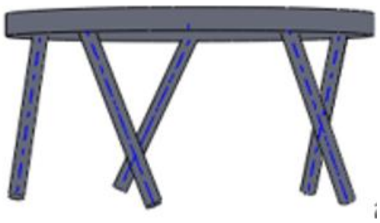

Figure 1. Electronic board with 5 legs

Using the relationship between force and displacement in a linear spring, the equivalent stiffness for each of the legs is calculated as:

$$K_{eq1} = \frac{1}{\frac{\cos^2(\alpha)\, l^3}{3EI} + \frac{\sin^2(\alpha)\, l}{EA}} \qquad (1)$$

When the leg moves in the y direction (horizontal direction), an angular displacement of θ will be created due to symmetry. Equation (2) expresses θ angle.

$$\theta = \frac{\boldsymbol{\delta_V} K_{eq}\, sin(2\alpha)}{2R}\left[\frac{l^3}{3EI} - \frac{l}{EA}\right] \qquad (2)$$

The equivalent mass of the system can also be calculated from

$$M_{eq} = m_b + \bar{I}\left[\frac{K_{eq}\sin(2\alpha)}{2R}\left[\frac{l^3}{3EI} - \frac{l}{EA}\right]\right] + 5 * \left[\frac{m}{3} sin^2(\alpha) + \frac{33 * m}{140} cos^2(\alpha)\right] \qquad (3)$$

After calculating the equivalent mass and equivalent stiffness, the acceleration applied to the mass can be calculated using the equation for one degree of freedom. In this article, the shock is applied to the base as a half-sinusoidal shock. The half- sinusoidal shock equation is given in Eq. 4 [9].

$$\boldsymbol{\ddot{u}_b(t)} = A_0\left\{\sin\left(\frac{\pi t}{T}\right) U(t) + \sin\left[\frac{\pi}{T}(t - T)\right] U(t - T)\right\} \qquad (4)$$

In the above equation, A_0 is the amplitude of the shock and T is the duration of the shock.

3. Results and Discussion

In this section, first, the equivalent stiffness presented in this article has been verified with the finite element method. The results of the finite element method confirm the results of the analytical method. The effect of different geometrical parameters on the acceleration of the electronic board has been investigated. A shock with an amplitude of 3000g and a duration of 0.3 milliseconds [10] has been applied to the base of the system.

The angle between the leg and the horizontal direction is effective on the transfer acceleration. The diagram in figure 2 shows this effect.

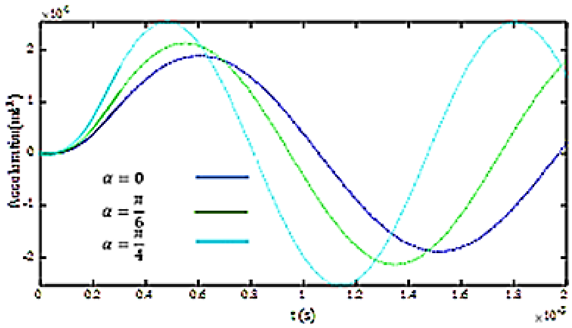

Figure 2. The effect of the angle of the legs on the acceleration of the electronic board

Another thing to consider is the excitation frequency. The acceleration-time diagram is drawn at different angles of the leg. The results of the graph shown in figure 3 show that changing the duration of shock at different angles does not have an equal effect. Therefore, the chosen angle of the leg should be proportional to the duration of the shock.

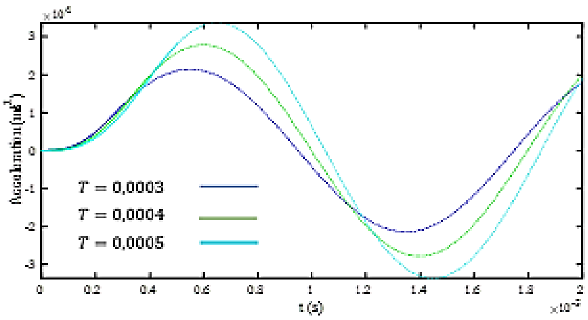

Figure 3. The effect of shock duration on the acceleration of the electronic board

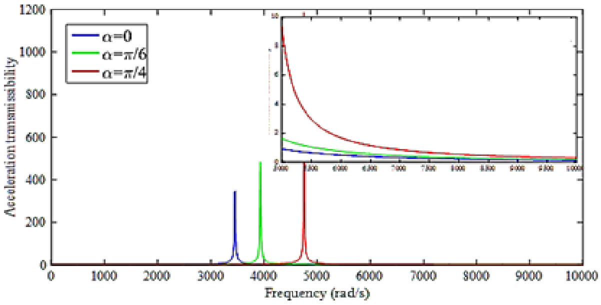

Figure 4. Acceleration transmissibility according to the excitation frequency

Figure 4 shows the transmissibility of acceleration depends on the ratio ω/ω_n. This diagram is drawn for 3 angles of 0, 30, and 45 degrees. Different parameters should be selected according to the range of excitation frequency. If the different parameters of the board are not selected correctly, the acceleration of the board will be higher than the input acceleration.

4. Conclusions

In this paper, the electronic board of the satellite guidance system, which is subjected to mechanical shock during separation or launch, has been analyzed analytically. Various parameters are effective in the transmissibility of the shock to the electronic board. These parameters include the geometry of the legs, the material of the legs, as well as the angle of the legs. The results of these investigations show that:

- Changing the angle of the legs respected to the horizontal direction changes the stiffness of the system, which in turn changes the transmissibility of acceleration according to the frequency of excitation.
- The equivalent stiffness of the leg is a function of the dimensions of the leg. Therefore, the equivalent stiffness changes with the change in the radius. The dimensions of the leg should be proportional to the angle of the leg so that the transmissibility of the acceleration in the system is within the desired range.
- Due to the dependence of the transmissibility of acceleration on the ω/ω_n, different parameters should be selected according to the range of excitation frequency. If the different parameters of the board are not selected correctly, the acceleration of the board will be higher than the input acceleration.

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