MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Research on passive vibration control of large honeycomb sandwich panel structure

Xinyin, Xu[1]
Institute of Systems Engineering, China Academy Of Engineering Physics
No. 64, Mianshan Road, Mianyang City, Sichuan Province, China

Boyang, Li[2]
Institute of Systems Engineering, China Academy Of Engineering Physics
No. 64, Mianshan Road, Mianyang City, Sichuan Province, China

ABSTRACT

Large flexible honeycomb sandwich panel structures are more and more used in the field of vehicle, and the vibration of it has become an important research topic. So a passive vibration control method without affecting the original function of honeycomb panel is proposed, in which a viscous damper is added at the root of the panel. The modal and transient response analysis proves that the passive vibration control of honeycomb sandwich panel can effectively improve the damping ratio of the structure but not reduce the fundamental frequency of it. The relationship between the attenuation velocity of vibration response of honeycomb sandwich panel and the damping coefficient of damper is researched, and the optimal damper coefficient is found. The influence of the damping ratio of honeycomb sandwich panel on the structural damping ratio after vibration control is studied. The results show that the introduction of passive dampers does not affect the strength and stiffness of the original structure, and can effectively suppress the vibration of honeycomb sandwich panel structure. When adding damper to a honeycomb sandwich panel with smaller self-damp the damping effect is more remarkable.

Keywords: Honeycomb sandwich panel structure, Passive vibration control, Viscous damper
I-INCE Classification of Subject Number: 15

1. INTRODUCTION

The development trend of modern solar panel is long life, high power and reliability. Making solar panels, as the energy source of communication vehicles tend toward large-scale, high flexibility, low stiffness, and weak damping,etc.[1]Solar panels are limited by their mass, usually used a high specific strength and stiffness structures such as Honeycomb sandwich panels.However, a large amount of vibration will be generated when the large honeycomb sandwich panel under the dynamic disturbance,

[1] xuxyin@qq.com
[2] 413liby@caep.cn

which will affect the normal operation of various payloads, resulting in system performance degradation or even failure, which directly threaten the safety of spacecraft structure.[2,3]Therefore, it is important to adopt effective measures to control the vibration of honeycomb sandwich panel structure to achieve the vibration reduction.

The vibration control methods include passive control and active control. Active control is able to achieve good vibration reduction effect,while additional energy equipment and more complex control devices are needed, and most of them have complex theoretical derivation and require strict control conditions[4]. Passive control has the advantages of simple structure, easy implementation, high reliability and good economy. It is the most widely used in vibration control even though the vibration damping effect can not meet the strict requirements. The successful passive vibration control applications example is the Hubble telescope [5], but the structure is the series damping mode, which inevitably reduces the fundamental frequency of the structure.

In this paper, a passive vibration control with parallel damping is applied on the honeycomb sandwich panels, and the fundamental frequency of structure is not reducing, this method of the passive damper is verified by simulation analysis.

2. PASSIVE VIBRATION CONTROL WITH PARALLEL DAMPING

The honeycomb sandwich panel structure is a cantilever structure. Adding a oblique member at the root of the honeycomb sandwich panel to improve the stiffness or damping of it, in order to suppress the vibration. The design model is shown in Figure 1. The hinged locking device is used between the damper and the connecting rod to improve the working reliability of the mechanism.

The simulation results show that the stiffness of honeycomb sandwich panel can be increased and the first-order modal frequency can be increased after adding oblique member at the root of it. But the improvement of the first-order modal frequency is limited and the effect of Vibration suppression is not good.

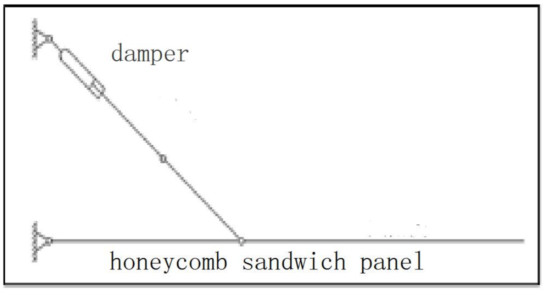

Figure 1 Design Diagram of Connecting Rod Damping Device

3. FINITE ELEMENT MODELING AND ANALYSIS OF ORIGINAL HONEYCOMB SANDWICH PANEL STRUCTURE

3.1 Finite Element Modeling

A finite element model of honeycomb panel is established based on references [6] and [7] , the bush element is used for the root hinge and inter-board hinge, the space beam element is used for the connecting frame, and the substrate is the shell unit.

Using the parameters from references [8], [9] and [10], the dimensions and material parameters required to establish the Patran model of the honeycomb sandwich panel are determined.

3.1.1 Honeycomb Sandwich Panel Structure

The span of the connecting frame is 1408mm, and the angle between the main beams is 60°. The beam element the square tube,the dimension of cross-section is 30 × 30mm, the thickness is 3mm, and the material is aluminium alloy. The length of the connecting frame support is 200mm and is solid beam element, the dimension of cross-section is 30×30 mm. The material is steel.

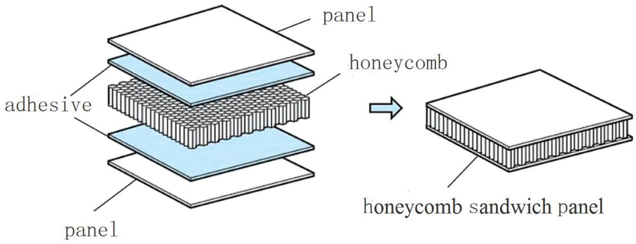

Figure 2 Honeycomb Sandwich Panel

The base panel is a honeycomb sandwich panel, as shown in Figure 2. The overall size of each panel is 2258×1826×30mm. The thickness of upper and lower panels is 0.3mm, and each with three layers, M40 carbon fiber/epoxy composite material is used. The interlayer is hexagonal aluminum honeycomb with a thickness of 0.04mm and a side length of 4mm. According to the sandwich panel theory, the interlayer is equivalent to an continuous orthotropic structure. The laying mode of the base panel is 45/0/-45/0/-45/0/45.

Both the root hinge and the inter-panel hinge are BUSH element, the length is 80mm , and the hinge stiffness is entered directly.

According to the data above, the original honeycomb sandwich panel structure after onfloding is established as shown in Figure 3, which including root hinge, 3 pairs of inter-panel hinge, 3 base panels and 1 connecting frame.

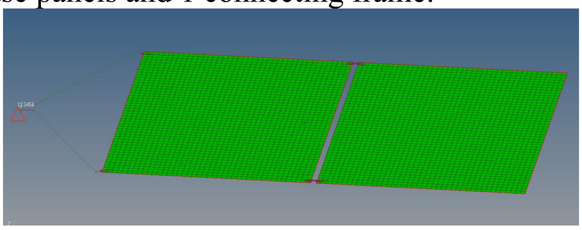

Figure 3 Original Honeycomb Sandwich Panel Model

3.1.2The Material of Honeycomb Sandwich Panel Structure

The performance parameters of aluminium alloy and steel are shown in Table 1.

Table 1 Performance parameters of metal materials

Parameters	Aluminium Alloy	Steel
E_s/GPa	71.7	207
ρ /(kg·m^{-3})	2740	7801
μ_s	0.33	0.29

The performance parameters of M40 carbon fiber/epoxy composites are shown in Table 2.

Table 2 Performance parameters of M40 carbon fiber/epoxy resin

parameters	value
E_{11}/GPa	240
E_{22}/GPa	7
G_{12}/GPa	4.6
ρ /(kg·m^{-3})	1640
μ_s	0.3

According to sandwich sandwich panel theory[11], the equivalent elastic constants of honeycomb interlayer can be get by the following formulas:

$$E_{11}=E_{22}=\frac{4}{\sqrt{3}}\left(\frac{t}{l}\right)^3 E_s\,,E_{33}=\frac{2}{\sqrt{3}}\frac{t}{l}E_s$$

$$G_{12}=\frac{3\gamma}{\sqrt{2}}\left(\frac{t}{l}\right)^3 E_s \qquad \text{Equation 1}$$

$$G_{31}=\frac{\gamma}{\sqrt{3}}\frac{t}{l}G_s\,,G_{23}=\frac{\sqrt{3}\gamma}{2}\frac{t}{l}G_s$$

$$\rho=\frac{8}{3\sqrt{3}}\frac{t}{l}\rho_s\,,\mu_{12}=\mu_S$$

Where γ is generally chosen between 0.4 and 0.6 in practice. Here, it is 0.5. E_s , G_s , ρ_s and μ_s are Young's modulus, shear modulus, density, and Possion ratio for the interlayer, respectively. So, the performance parameters of equivalent honeycomb interlayer material is shown in Table 3.

Table 3 Performance parameters of equivalent honeycomb interlayer material

parameters	value
E_{11}/MPa	0.165584
E_{22}/MPa	0.165584
E_{33}/MPa	827.9
G_{12}/MPa	0.031047
G_{23}/MPa	77.94
G_{31}/MPa	116.9
ρ /(kg·m^{-3})	42.158
μ	0.33

Based on reference [12], the equivalent stiffness of root hinge and inter-panel hinge in six directions are shown in Table 4.

Table 4 Equivalent Stiffness of Root Hinge and Inter-panel Hinge in Six Directions

Direction	Root hinge	Inter-panel hinge
X/(N·m^{-1})	3240000	7428000
Y/(N·m^{-1})	266000	993600
Z/(N·m^{-1})	357000	517200
R_X/(N·m·rad^{-1})	1680	1104
R_Y/(N·m·rad^{-1})	5558	792
R_Z/(N·m·rad^{-1})	58600	54840

3.2 Analysis

The Modal analysis of honeycomb panels under cantilever state is obtained by fixing the freedom of the end points of the root hinge.The modal frequencies of the first ten steps are shown in Table 5.

Table 5 The sixth modal frequency of the original honeycomb sandwich panel

Order	Modal frequency(Hz)	Order	Modal frequency(Hz)
1	0.173	4	0.762
2	0.253	5	1.546
3	0.434	6	1.996

According to the modal analysis, a sinusoidal excitation $f(t)=\sin(0.4\pi t)$ with a frequency close to the first-order modal frequency of honeycomb sandwich panel model is applied at the midpoint of free end, and the action time is 0.5s.

Using direct method to the transient response analysis. The damping ratio of Model is ξ. According to the analysis, the relationship between viscous damping and structural damping is $g=2\xi$. Therefore, set the overall structure damping coefficient g to twice the structural damping ratio ξ in Patran. But the damping force of viscous damping and structural damping is the same only at a certain frequency. The damping force at resonance is the most significant. Therefore,this particular frequency is usually set at the first mode resonance frequency, i.e. W3, the value of Damping Factor is $W3=2\pi f_1$. The analysis step is 1000 and the step length is 0.1s.

The structural damping ratio is 0.5%, the displacement response curve of the applied point of honeycomb sandwich panel is obtained as shown in Figure 4. The first five seconds are forced vibration, then is free vibration. In the process of free vibration, the amplitude of displacement response decreases due to the presence of structural damping.

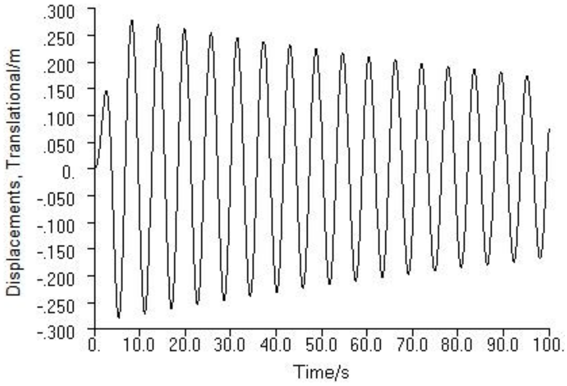

Figure 4 Original honeycomb sandwich panel force point displacement response curve

4 FINITE ELEMENT MODELING AND ANALYSIS OF HONEYCOMB SANDWICH PANEL WITH PASSIVE DAMPING

4.1 Finite Element Modeling

Based on the original finite element model of honeycomb sandwich panel in 2.1, the finite element model of parallel damped honeycomb sandwich panel is established by adding oblique damper element at the root, as shown in Figure 5. The damping element is modeled by Viscous Damper.

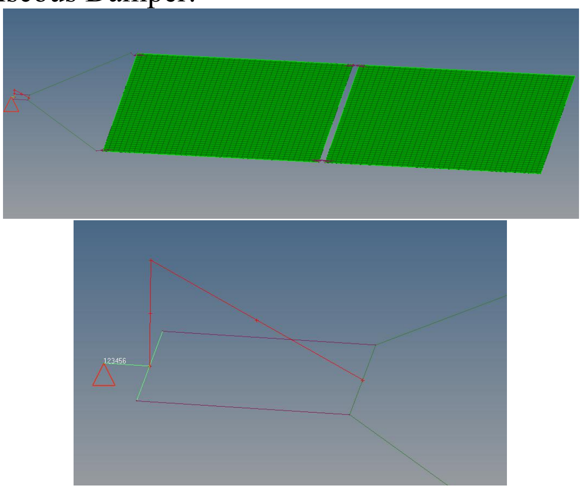

Figure 5 Finite Element Model of Honeycomb Sandwich panel with

Additional Parallel Damping

4.2 Analysis

No matter how the damping coefficient of the damping element change, the first-order modal frequency is still f_1=0.173Hz. Therefore, the parallel damping will not reduce the fundamental frequency of the structure.

The transient response analysis is performed with the same sinusoidal excitation and parameter setting as before. The damping coefficients are 200 000 Ns/m, 300 000 Ns/m and 50 000 Ns/m, respectively. The displacement response curves of the free end are shown in Figure 6. When the damping coefficient of the damping element is different, the amplitude attenuation speed is different. Firstly, The amplitude attenuation speed increases with the increase of damping coefficient. When the damping coefficient increases to a certain value, the amplitude attenuation is the fastest, and then the damping coefficient continues to increase, the amplitude attenuation speed will slow down. This indicates that there is an optimal damping coefficient.

After comparison and analysis, the optimum damping coefficient of the damper element is about 300000 Ns/m.

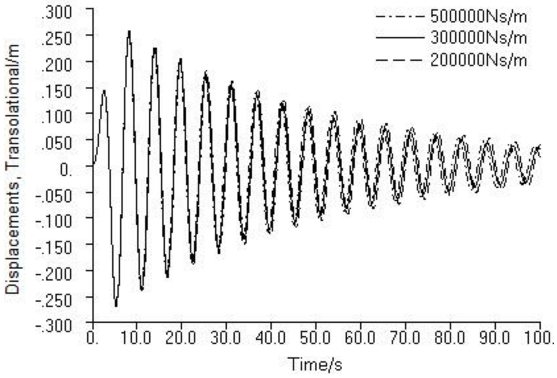

Figure 6 Displacement response curves of honeycomb sandwich panel with additional parallel damping

The damping ratio of the system can obtain by using the free attenuation method from the free vibration displacement response curve. The solution formula is as follows:

$$\delta = \frac{1}{n}\ln\left(\frac{x_1}{x_{n+1}}\right), \quad \xi \approx \frac{\delta}{2\pi} \qquad \text{Equation 2}$$

In the formula, δ is logarithmic attenuation rate, ξ is damping ratio, n is the interval period of the amplitude, x_1 and x_{n+1} are corresponding amplitudes, respectively.

According to Equation 2, when the damping coefficient of the damper element in Figure 6 is 300000 Ns/m, the damping ratio of the system is about 2.1%, which is 4.2 times as large as the original one. This indicates the damping ratio of the original structure is greatly improved by adding parallel damping. And the passive control method is effective for the honeycomb sandwich panels vibration reduction.

4.3 The Influence of Structural Damping Ratio

Changing the overall structural damping ratio of honeycomb sandwich panel model, the setting of other parameters and excitation is same as the previous one. The transient response analysis was performed to research the influence of damping ratio on the vibration reduction of the honeycomb sandwich panel with additional damping.

The damping coefficient of the additional damping element is 300000Ns/m, setting the structural damping ratio of the whole honeycomb sandwich panel model is 1% and 2%. The displacement response curves of the force applied points are shown in Figure 7 and 8, respectively.

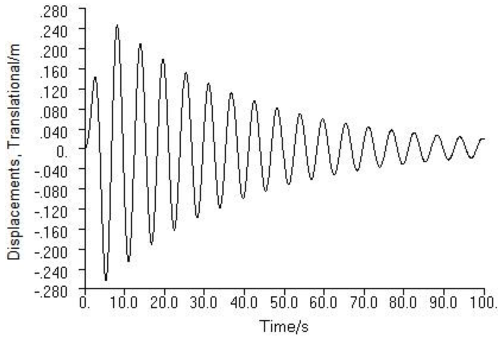

Figure 7 Displacement Response Curve of Force Point at 1% Damping Ratio of Structures

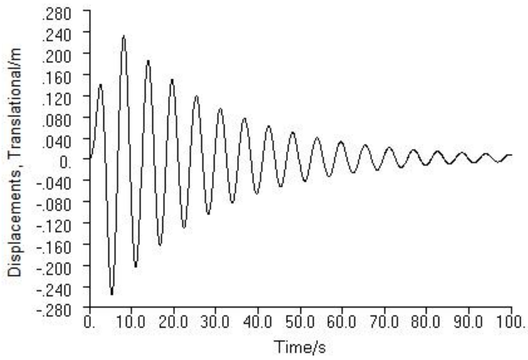

Figure 8 Displacement Response Curve of Force Point at 2% Damping Ratio of Structures

4.4 Result analysis

When the damping ratio of the original structure is 1%, the damping ratio can increase to 2.5% after adding parallel damping, which is 2.5 times as large as the original structure. When the damping ratio of the original structure is 2%, the adding parallel damping increase the damping ratio to 3.6%, which is 1.8 times as large as the original.

According to the analysis results in 4.2, when the damping ratio of the original honeycomb sandwich panel structure is small, the increase of the structural damping ratio after adding parallel damping is more significant than that of the original structure.

Under the two damping coefficients, the damping ratio can be increased about 4.5%, up to 9 times, which is only 10% less than the optimal state, and the effect of vibration reduction is still obvious. The practicability of the damper is verified.

5 CONCLUSION

1)Through modal analysis and transient response analysis, the fact that passive control design of parallel damped honeycomb sandwich panel does not reduce the fundamental frequency of the structure is verified. It is proved that the damping ratio of the structure is effectively improved, and vibration reduction effect for honeycomb sandwich panel is good.

2)The amplitude attenuation speed of the honeycomb sandwich panel is speed up firstly, then slow down with the damping coefficient of the parallel damping at the root is increasing. For different honeycomb sandwich panels, there is an optimal damping coefficient for parallel damp.

3)The influence of the original structure damping ratio of honeycomb sandwich panel on the increase of the structure damping ratio after adding the parallel damping is clarified. The damping ratio of the original structure is smaller,after adding the parallel damping, the damping ratio of new structure increase significantly than the larger one.

4)The parallel damping system was designed and manufactured to be applied at a honeycomb sandwich panel, and the operability of the dampers is verified. In the future, relevant experimental research will continue.

6. REFERENCES

1. P． Alan Jones and Brian R． Spence, “Spacecraft Solar Array Technology Trends”, IEEE Aerospace Application Conference Proceedings,United States： IEEE， 1998： 141-152.

2. Zheng Gang, “Research progress on vibration isolation and vibration suppression of spacecraft”, Papers of the Ninth National Symposium on Vibration Theory and Application, Zhejiang University, 2007.
3. E．V．Morozov，A．V． Lopatin, “Design and analysis of the composite lattice frame of a spacecraft solar array”,Composite Structures，2011，93(7)：1640-1648．
4. Liu Qiang, He Wenjie, Tang Guoan, “Vibration control theory and Simulation of honeycomb sandwich panel driven by motor”. Vibration and impact, 2009, 28 (12): 119-122.
5. S．M．Anandakrishnan，C．T．Connor，S．Lee， et al, “Hubble Space Telescope Solar Array Damper for Improving Control System Stability”． IEEE Aerospace Conference Proceedings, United States：IEEE，2000：261-276．
6. Jiang Jianping, Li Dongxu, “Dynamic honeycomb modeling and modal analysis of intelligent honeycomb sandwich panels”. Chinese Space Science and Technology, 2008, 4: 32-39.
7. Wu Yuanbo, Du Jianghua, “Solar cell array hinge mechanism stiffness equivalent method”. Spacecraft Environmental Engineering, 2010, 27(4): 467-471.
8. Chen Liemin, “Cellular sandwich panel expansion motion analysis”. Chinese Space Science and Technology, 1992, 2: 21-26.
9. Chen Liemin, “Spacecraft structure and mechanism”. Beijing: China Science and Technology Press, 2005: 102-111, 187-188.
10. Zhang Tieliang, Ding Yunliang, Jin Haibo, “Comparative analysis of equivalent model of honeycomb sandwich panel structure”. Journal of Applied Mechanics, 2011, 28(3): 275-282.
11. Gibson L J, Ashby M F, “The Mechanics of Three-Dimensional Cellular Materials”. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 1982, 382(1782):43-59.
12. Zhang Lei, “Design and research of spacecraft distributed expansion honeycomb sandwich panels”. Shanghai: Shanghai Jiaotong University, 2012.