Dynamic Testing and Analysis of Self-Supporting Inflatable Beams

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Summary Dynamic testing of an inflatable self-supporting beam has been performed to evaluate structural natural frequencies and modal damping ratios. The thin-film structure has a pattern of six composite fiber straps that increases the local stiffness of the point that the structure is self-supporting in the gravity environment of Earth when the internal pressure is released. A measurement setup was installed, and the dynamic testing was performed in this self-supporting state. Dynamic characters of the beams were tested with internal pressure or not when the beam had a 2.0kg mass on the top. Moreover, the dynamic characters before rolled up were contrasted to one after. The experimental results indicate that the self-supporting inflatable beams had better bending stiffness, and the curl folding process had an impact on the dynamic characteristics of the self-supporting inflatable beam. The pressure affection is not obvious on dynamics of the beam.

INTRODUCTION

Inf1atable space structures have been accepted by more and more scholars because they can meet structural requirements for space applications at a low cost and reliable deployment. Moreover, several space missions have considered the use of the lightweight inflatable structures for components such as antennas [1], solar sails, sunshades, solar concentrators, and solar array [2] in the ITSAT project for many aspects of earth and space explorations.

A common approach to these inflatable space structures starts with a basic component referred to, or known as, inflatable beams. They are the basic building blocks of these structures and are characterized by being long, tubular inflatable beams and struts. The advantages they bring are that in general they are flexible and can be rolled up or folded to achieve high packing efficiency. After the desired orbital location has been reached the stowed beams are inflated and deployed by internal pressurization to attain their intended geometrical shape. At this point there are two main types of inflatable beams. One in which the stiffener is maintained to keep the beam in its intended shape or the other that rigidizes and eliminates the need for internal pressure. This research focuses mainly on a stiffener beam, that’s to say self-supporting beams.

Dynamic testing of an inflatable self-supporting beam has been performed to evaluate structural natural frequencies, and modal damping ratios. The structure presented two unique challenges with respect to modal testing. Firstly, it is extremely lightweight, flexible, and highly damped. Secondly, the thin film that provide the integrity to the structures is not smooth and flat, but has a pattern of six composite fiber straps that increases the local stiffness of the point that the structure is self-supporting in the gravity environment of Earth when the internal pressure is released. Vibration is a great concern in large space inflatable structures. Once deployed, these inflatable structures are subject to vibrations that can be induced mechanically by satellite repositioning, in order to control these space structures it is often necessary to dynamics testing. Griffith and Main [3] and Park et al. [4] performed experimental investigation into the dynamics of an inflated torus. Smalley and Tinker [5] have studied the dynamic behavior of an inflated beam. They have modeled the effect of the enclosed fluid by adding non-structural mass to the shell elements. Srivastava et al. [6] developed a realistic model, and dynamic interaction between the enclosed fluid and the torus has been included. It is concluded that fluid–structure interaction significantly affects the dynamic behavior of inflatable space structures.

Such a beam can be packed in a small volume and deployed into an upright configuration, and thus is a suitable candidate for future missions involving space inflatable structures. In this paper, a measurement setup was installed, and dynamic characters of the beams were tested with internal pressure or not when the beam had a 2.0kg mass on the top. Moreover, the dynamic characters before rolled up were contrasted to one after. It demonstrates that the self-supporting inflatable beams had better bending stiffness. This paper summarizes the results of the ground dynamic testing and recommends next steps in inflatable beam technology development.

TEST RESULTS AND ANALYSIS

In order to investigate the performance of inflatable, two kinds of the dynamic test is carried out in laboratory. One condition is with 40kPa inner gas pressure plus 2kg payload at the free end, and another condition is 0kPa inner gas pressure plus 2kg payload. Because composite fiber straps reinforced inflatable beam is also a self-rigidaziable structure, when it was unrolled, it can also bear 2kg compression payload in axial direction with or without inner gas pressure, so the configuration is in vertical state with 2kg compress payload. Applying dynamic signal analyzer for collect and analysis signal from acceleration mounted at the free end. Since membranes have itself unique flexible property, it can not be excited with a hammer or electrical excitation. Beside, the natural frequency of the inflatable beam is very low, especially with lumped mass at the free end. So step excitation is used, that is applying initial displacement at the free end of inflatable beam, acquire the free response of acceleration and analyzer spectrum by FFT method. From the spectrum peak point, we can get the natural frequency of the beam under this initial condition. As

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inflatable beam is rolled up before rocked off, and finally deployed at space orbit, so it is also need to evaluate how rolled up influence the performance of inflatable beam. In Tab. 1 shows the experimental results.

From Tab. 1, the inner gas pressure can slightly change the bending natural frequency of inflatable beam, with and without gas pressure, the X and Y direction bending natural frequency almost the same, but change the torsion natural frequency in relatively. After 1st time rolled up, the frequency reduced apparently from 0.961Hz to 0.778Hz with 2kg lumped mass plus 40kPa inner gas pressure. When the inner gas pressure is taken off, one bending frequency is increased from 0.778 Hz to 0.824Hz, and another bending is decreased from 0.778 Hz to 0.732Hz, different from the condition before rolled up, but still more than 0.5Hz in assignment.

This shows that the process of this mode had an impact on the dynamic characteristics of the self-supporting inflatable beam. If the beam is not folded, the beam cross-section can maintain the circular cross section with or without inflation pressure, so the pressure affection is not obvious on dynamics of the beam. If the beam is folded through the curled mode, as the release of internal gases, because there produced plastic deformation nearby the folded line, moreover, the rolling procedure occurred damage along the line, the beam cross-section is no longer circular, but elliptical. Therefore, this bending frequency for X-direction with 0kPa increases and with 0kPa Y-direction bending frequency reduces.

Tab. 1 Dynamic test results

	Test condition	Frequency Hz
Before rolled up	2kg, 40kPa X-direction bending	0.961
	2kg, 40kPa Y-direction bending	0.961
	2kg, 40kPa Torsion	10.895
	2kg, 0kPa X-direction bending	0.960
	2kg, 0kPa Y-direction bending	0.960
	2kg, 40kPa Torsion	9.430
After rolled up	2kg, 40kPa X-direction bending	0.778
	2kg, 40kPa Y-direction bending	0.778
	2kg, 40kPa Torsion	10.712
	2kg, 0kPa X-direction bending	0.824
	2kg, 0kPa Y-direction bending	0.732
	2kg, 40kPa Torsion	7.782

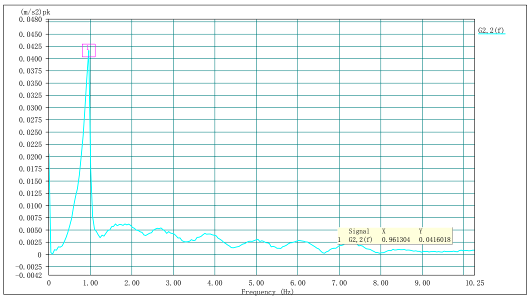

Fig. 1 the self-spectrum of bending vibration

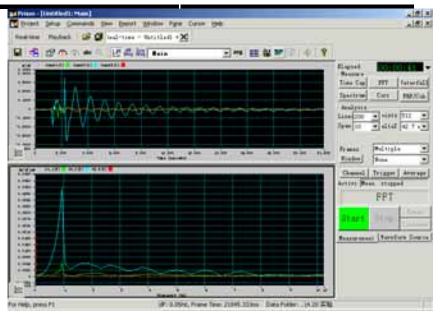

Fig. 2 the interface of bending vibration

CONCLUSION

Dynamic testing of an inflatable self-supporting beam has been performed to evaluate structural natural frequencies, and modal damping ratios. The structure presented two unique challenges with respect to modal testing. Firstly, it is extremely lightweight, flexible, and highly damped. Second, the thin film that provide the integrity to the structures is not smooth and flat, but has a pattern of six composite fiber straps that increases the local stiffness of the point that the structure is self-supporting in the gravity environment of Earth when the internal pressure is released. The dynamic testing was performed in this self-supporting state. The experimental results indicate that the curl folding process had an impact on the dynamic characteristics of the self-supporting inflatable beam. If the beam is not folded, the beam cross-section can maintain the circular cross section with or without inflation pressure, so the pressure affection is not obvious on dynamics of the beam. If the beam is folded through the curled mode, as the release of internal gases, because there produced plastic deformation nearby the folded line, the beam cross-section is no longer circular, but elliptical. Therefore, this bending frequency for X-direction increases and Y-direction bending frequency reduces within no pressure. Further work should consider whether structural damping applied at flexible deformation should be reconsidered at such a self-supporting beam.