A Study about Spin Extension of Three-dimensional film Structure

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Abstract

On spin type film structure, when membrane device such as liquid crystal device, film antenna and film solar cell are loaded, there are limited within plane. Pop-up mechanism enables to load them on base film three dimensional. This study conducted gravity environmental experiment, vacuum chamber experiment and FEM analysis on the shape of three-dimensional membrane surface structure, we will clarify the number of stages and membrane rigidity for three-dimensionally mounting liquid crystal devices which are expected to be installed in the next solar power sail.

立体型膜面構造物のスピン展開に関する研究

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摘要

スピン型薄膜構造物において膜面デバイス（液晶デバイス，膜面アンテナ，薄膜太陽電池など）を搭載する際には平面上に限られてくる．ここでベースフィルムに飛び出す絵本のような仕掛けを施すことによって，膜面デバイスを立体的に搭載することができる．本論文では，立体化膜面構造物の形状について，重力環境試験，真空槽試験と FEM 解析を比較し，次期ソーラー電力セイルへの搭載が考えられている液晶デバイスを立体的に搭載するための搭載段数や膜剛性を明らかにする．

１．background

Example of spin type film membrane, 14m×14m size of square, demonstration equipment of solar electric sail「IKAROS[1]」is mentioned. IKAROS extended membrane device such as film solar cell, liquid crystal device and dust counter. These are loaded on plane of the sail. It is figured Fig. 1.1. ,by applying mechanism pop-up on base-film, membrane device it is restricted to loading on plane enables to load them on base film three dimensional.

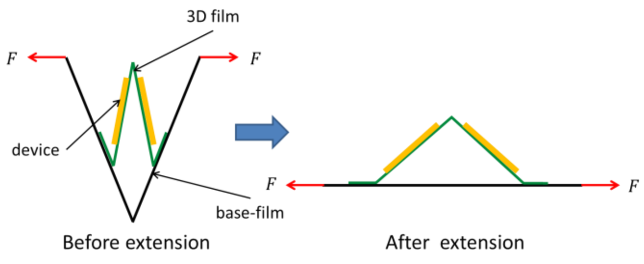

Fig. 1.1. Design of loading three-dimensional thin-film structure.

This research considers loading liquid crystal device(RCD) with the sail on three dimensional. RCD[1] is device that can be changed reflectivity by ON/OFF of power. Fig. 1.2. shows control of altitude by RCD. Power ON, specular reflection is mainly dominant. On the other hand, Power OFF, diffuser reflection is mainly dominant. IKAROS successed changing control of altitude only SRP by loading this device with periphery of solar sail without slaster. But, this method cannot control spin rate. IKAROS was found wind mill effect(2) spin rate changes by torsion of film, but IKAROS returned spin rate changed by wind mill effect by thruster. Fig. 1.3. shows windmill effect that generates by torsion of film membrane.

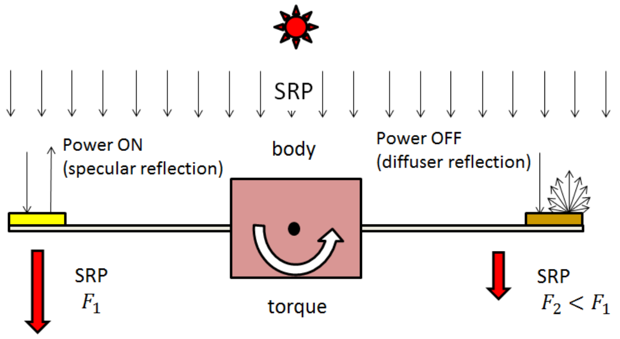

Fig. 1.2. Controlling attitude of IKAROS by RCD.

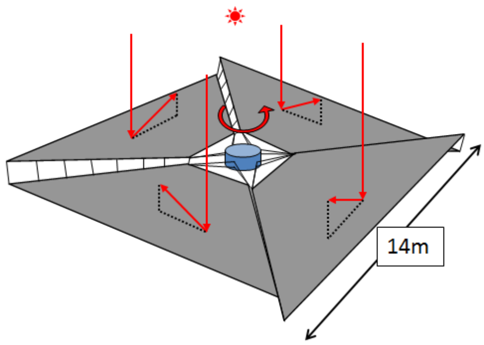

Fig.1.3. Wind mill effect.

JAXA is considering plan of solar electric power sail in the early 2020's, based on results of IKAROS. Size of square solar electric power sail is 50m, about 3.5 times of size of IKAROS. Purpose of the solar sail is sample return to Jupiter Trojan asteroid. The larger size of the solar sail is, the bigger windmill effect is. So we must load several hundred fuels to recover spin rate by windmill effect.

By applying a three-dimensional membrane film-structure and thinking of stereoscopically mounting a liquid crystal device, it becomes possible to control the spin rate and it is possible to cancel the windmill effect only by SRP without using fuel .Fig. 1.4 shows controlling of spin rate when RCD loads in three dimensional.

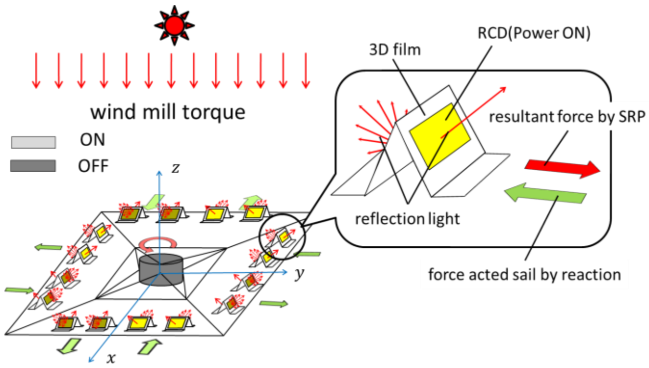

Fig. 1.4. Loading on RCD in three dimensional.

In this study, compares gravity environmental experiment, vacuum chamber experiment and FEM analysis to compare the form of three dimensional thin-film structures were conducted and reveal to spin rate, film rigidity to load liquid crystal device three dimensional that loading for next solar electric sail is thought.

2. Experiment of gravity environment

We cut polyimide of different three type's size and expose gravity environment. In Figure 2.1, centrifugal force loaded on the actual membrane surface is simulated by gravity by attaching the cut membrane to the wall. To compare changing of shape with FEM analysis, We define near side of top of 3D film, point A, back side of top of 3D film, point B. FEM analysis soft is Abaqus. The model simulated modeling by shell element experiment of gravity environment by the soft. This analysis model carried out experiment and analysis without loading simulated film membrane.

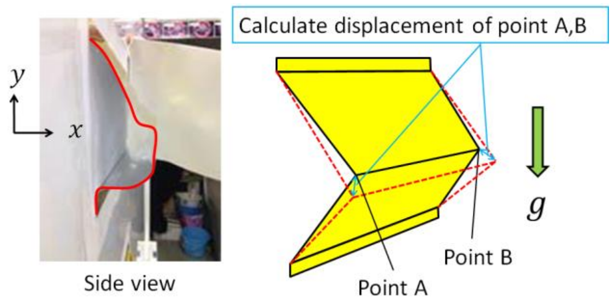

Fig. 2.1. Gravity environment experiment FEM analysis model.

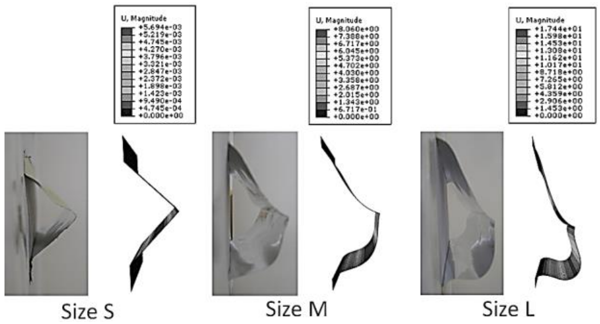

Fig. 2.2. Comparison result of extension experiment and FEM analysis.

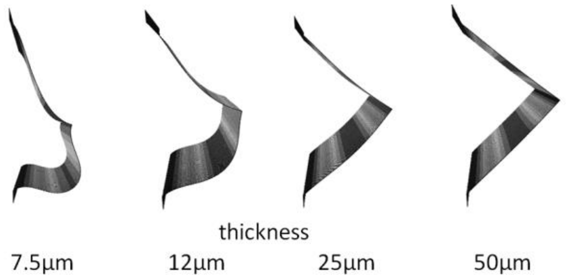

Fig. 2.3. Changing of thickness in FEM analysis.

Table 2.1. Comparison experiment value and analysis value(size S,M,L).

		displacement of right angle point(mm)			
		experiment value		analysis value	
sampleNo.	point	x	y	x	y
S-1	A	0.5	-0.6	0	0
	B	0.1	-1.1		
S-2	A	0.1	0.2		
	B	-1	0.1		
M-1	A	-0.8	1.7	-7.2	4.3
	B	-2.6	4.3		
M-2	A	-3.9	2.3		
	B	-2.9	3.3		
L-1	A	-4.5	2.6	-14.2	8.4
	B	-6.3	2		
L-2	A	-8.8	4.8		
	B	-7.1	5.6		

Figure 2.2 shows the experimental values from the left for each membrane size, and the analysis results on the right. A qualitative agreement is found when comparing the experiment and the FEM analysis, and the smaller the size of the film, the easier it is to maintain the shape. Table 2.1 summarizes experimental values and analytical values by measuring displacement of points A and B in film of different sizes. As a result of comparison between experiment and analysis, an error was seen. Manufacturing errors and pasting errors when pasting on walls can be cited. In addition, since rigidity is partially increased by attaching a crease, there is a possibility that it can approach the analysis value by devising a crease. Figure 2.3 shows FEM analysis with film size fixed and film thickness changed. It is understood that the larger the film thickness, the easier the shape is maintained. By comparing these experiments and analyzes, it was possible to qualitatively confirm the validity of the results of FEM analysis.

3. Sun radiation pressure torque

We evaluated torsion of film from windmill torque of flight data of IKAROS qwantively, applied the value to shape of next solar electric sail, and calculated predicted windmill torqueT_z. Therefore, we verify the possibility of canceling the wind mill torque of Torque $T_z{}'$ that can be controlled by stereoscopically mounting RCD. In this example, consider the case where the RCD is mounted in two stages as shown in Fig. 3.1. However, when multiple stages are mounted as shown in Fig. 3.2, if adjacent three-dimensional membrane surfaces are too close, a phenomenon, called secondary reflection occurs in which light reflected by the three-dimensional membrane surface once enters the adjacent three-dimensional membrane surface. In this study, we calculated $T_z{}'$factor taking into account the condition that secondary reflection does not occur.

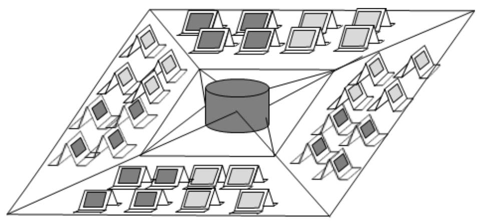

Fig. 3.1. Loading on RCD in multiple steps in three dimensional. (ex: two steps)

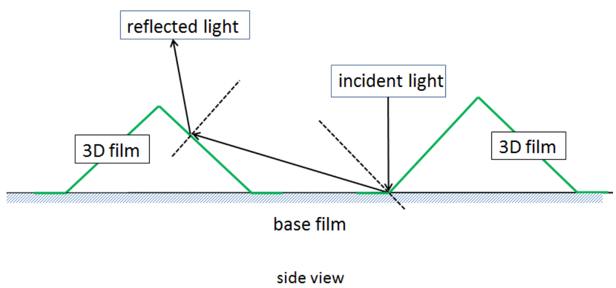

Fig. 3.2. Secondary reflection.

Integral value of T_z was calculated T_z=52.577N・m・day from flight data of IKAROS. In addition, the wind mill torque T_z can be controlled $T_z{}' = 55.518$ N · m · day. Therefore, it was confirmed that the torque which changes the spin rate by the windmill effect can be canceled only by SRP by stereoscopically mounting the RCD.

4. Conclusion and future works

We suggested extension film membrane device of spin type thin-film structure in three dimensional. For example, we considered loading RCD in three dimensional. Also, we confirmed shape of 3D film membrane structure by experiment and analysis when sail extends. In fact, we confirmed size of torque when RCD was loaded in three dimensional.

In the future, we will conduct a test to confirm the shape of the three-dimensional membrane film-structure during expansion in a vacuum state close to the actual space environment. Also, we experiment and analyze whether we can rise from the collapsed state or the collapsed state at the time of deployment. From the above results, we will build flight model and reveal condition(size, thickness, step, etc.…) of 3D film will loaded on next solar electric power sail.

Reference

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(2) Youji Shirasawa et.al, Evaluation of sail membrane behavior in low spin / inverse spin operation of IKAROS, The 12th Space Science Symposium, (2012), pp. 3-55.