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DEVELOPMENT OF SPACE BOOM FOR MICRO-SATELLITE: DESIGN OF PIN-PULLER AND VIBRATION TEST

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Abstract

The present paper describes mainly the development of a pin-puller for a space boom to be installed on a 50 kg-class micro-satellite, tentatively called as SOHLA-1. The total mass of the boom system is 280 g, while the length is 425 mm. A pin-puller is a most important component for launch-rock and release mechanism of a space boom. Firstly proposed was a new type of pin-puller, a spring-string type pin-puller. A bread-board model (BBM) of a boom accommodated with a pin-puller was tested on a shaker bed in transverse direction to find that a dummy mission component at the tip end, with the mass of 100 g, was subjected to severe rotational motion around the pin as a centre of rotation. This was because of a distance between the dummy mass and the pin. Then an engineering model (EM) of pin-puller was designed to suppress the rotational motion by adopting two pins, though a normal pin-puller has a single pin. Vibration test of pin-puller EM was conducted to find that rotational motion of the dummy mass was suppressed considerably. Through vibration test and space environment test, a pin-puller and thus the boom was redesigned to make a proto-type model. Thus the paper describes how the vibration test was of vital importance in developing and refining a pin-puller and a space boom as well.

INTRODUCTION

The paper reports development of boom to be installed in a 50 kg-class micro-satellite, code-named “SOHLA-1” and scheduled to be launched in 2007. SOHLA-1 is a Japanese version of so-called “smaller-faster-cheaper” piggy-back satellite to be developed upon civilian initiative. [1,2,3] Though there have been many micro-satellite developed in the past, a few of them is accommodated with a deployable boom. Most interestingly, the present boom is going to be developed upon student-initiative, including designing, machining and verification testing, so on. Figure 1 depicts an image of SOHLA-1 with two booms in their two configurations. Some details of SOHLA-1 are found in the sister article by Shirako et al..[4]

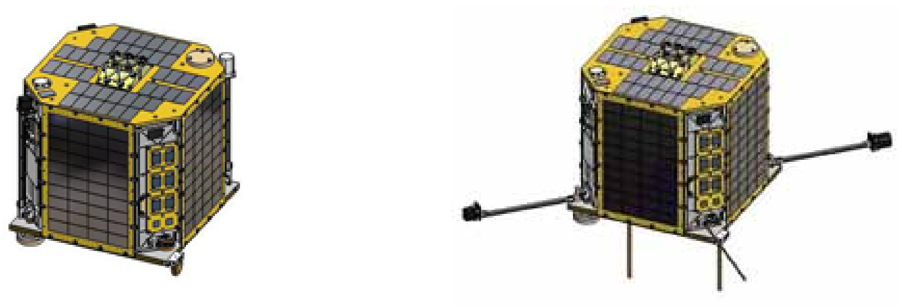


Figure 1 – Image of SOHLA-1 with booms
(Left: Booms folded. Right: Booms deployed)

Amongst many testing, vibration testing is the most important testing in the development of space mechanisms, herein a boom. The booms for SOHLA-1are folded and locked on the outer store-panels during launching and released to deploy in rotation on a command from the ground control center. For this action, a pin-puller is the key mechanism to make “launch-lock” and “release” action. Figure 2 shows a overview of the boom system with a boom folded and fixed on the outer store-panel. A mission device was assumed as a magnetic sensor of 100 g. A dummy mass for the sensor was fixed to the tip of the arm.

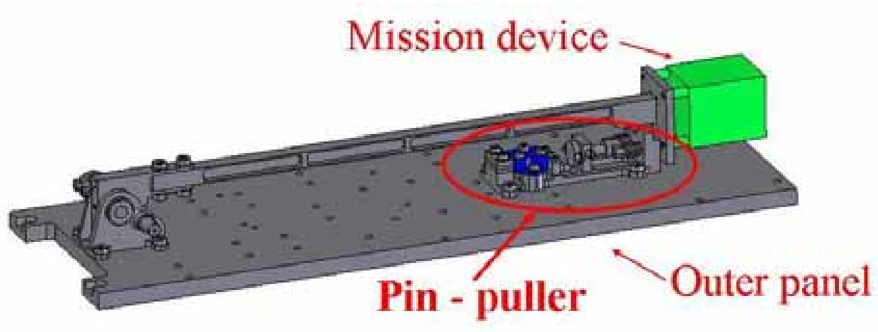


Figure 2 – Boom launch-locked on outer store-panel

DESIGN OF PIN-PULLER

The boom must be locked by a launch-lock pin during launching and released by pulling out the lock pin for deployment. Primary requirements for a pin-puller are as follows; 1. Reliable locking and releasing. 2. Light-weightedness. 3. Assured initial function and no damage after repeated operation. Several types of pin-puller, paraffin-type and shape-memory alloy (SMA) type, have been sold in space-market. A pin-puller in space market may cost nominally ten thousand US$ or so because of its high reliability. However a budget for the present micro-satellite project is limited so severely that a new simple type of pin-puller is demanded. Thus a spring-string type pin-puller is proposed for the present development of pin-puller. A pin-puller Bread Board Model (BBM), as shown in Figure3, was designed by taking account of the requirements. Launch-lock is hold by a tension given by strings, while a force to pull out the pin is actuated by an elastic restoring force of a spring. Figure 3 shows a boom BBM in preliminary design stage.

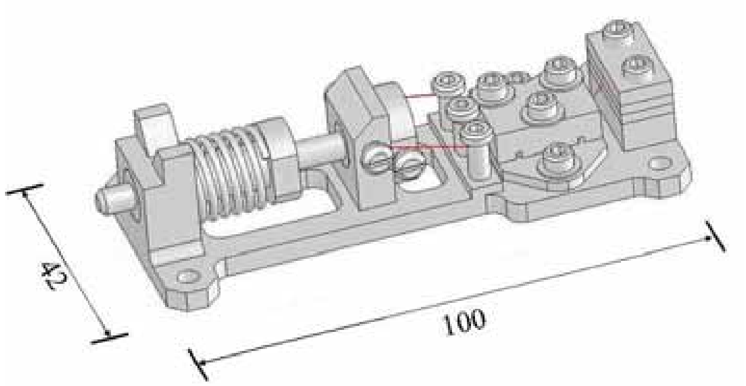


Figure 3 – Conceptual sketch of pin-puller BBM

To fabricate a spring-string type pin-puller, the mechanical characteristics of the string is the key for reality of this type of boom. A polyethylene fiber "Dyneema ®" was used as the string. The fiber has been applied in many severe environments, including in space.

Figure 4 demonstrates actuation and action of spring-string type pin-puller.The boom BBM was subjected to vibration testing to find that the dummy mass of mission component had a severe rotational motion around the lunch-lock pin. Figure 5 shows the rotational motion of the dummy mass observed when the excitation was given to the boom in *x* axis direction (as to x/y/z coordinates, see Figure 9).

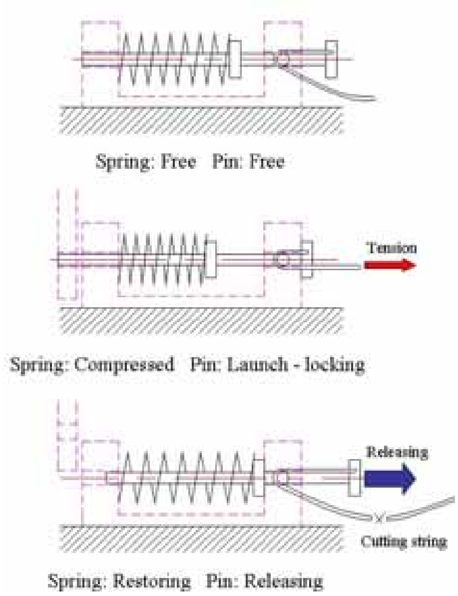


Figure 4 – Actuation and action of spring-string type pin-puller

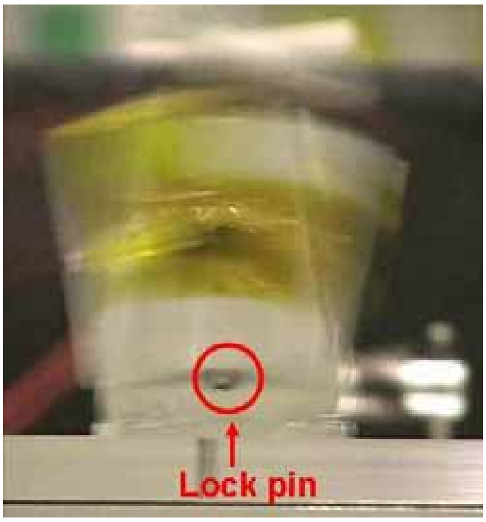


Figure 5 – Rotational motion of dummy mass due to x-axis excitation

In order to suppress the rotational motion around the pin, the pin-puller BBM was redesigned to make a two-pin type pin-puller EM, as shown in Figure 6.

Figure 6 – Two-pin type pin-puller EM

VIBRATION TESTING

Primary aims of vibration testing are as follows;

1. To verify reliability of the designed boom against mechanical environment during launching.
2. To confirm suitable vibration characteristics of the boom, especially eigen-frequencies and eigen-modes of the boom

Test boom was fixed on outer store-panel and the panel was fixed to the interface which joined the test boom-panel system and the shaker-bed. The interface plate was designed to have a high stiffness. As it is planned that the micro-satellite will be launched by a Japanese heavy launcher H-II A rocket, so the random and sinusoidal excitations(x, y, z axes) following H-II A characteristics were given to the test model. It is noted that the vibration testing with a space component should be done with pre and post low level excitation. To verify the effect of vibration testing, a pre-low-level-random vibration testing (pre-random vibration) shall be followed by post-low-level-random vibration testing (post-random vibration). By comparing the test results of the pre-random to the post-random test on the damage of vibration testing can be checked. This is the reason why the pre- and post random vibration testing shall be conducted in one set herein.
Figure 7 shows overall view of the test configuration. Test process is given in Figure 8.

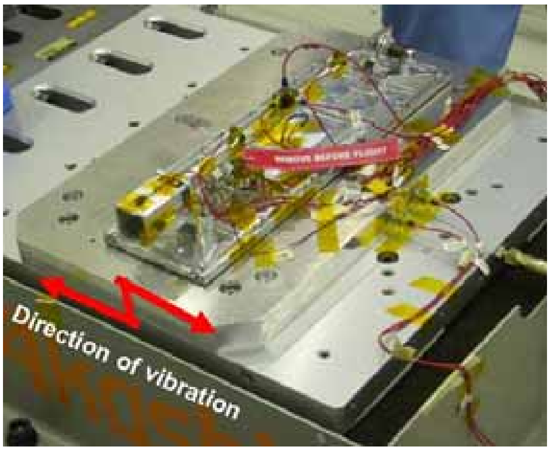


Figure 7 – Test configuration

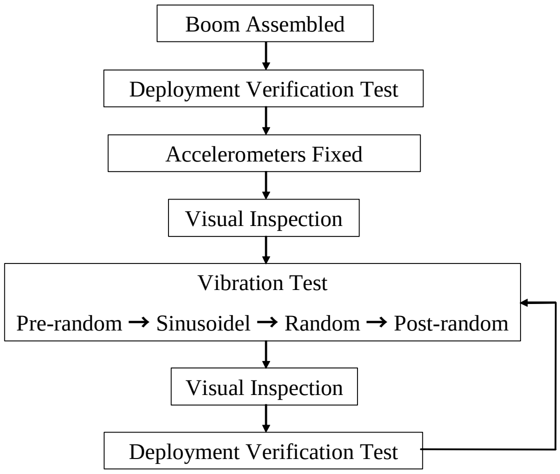


Figure 8 – Test process

Accelerometers were fixed at 10 positions on the boom as depicted in Figure 9.

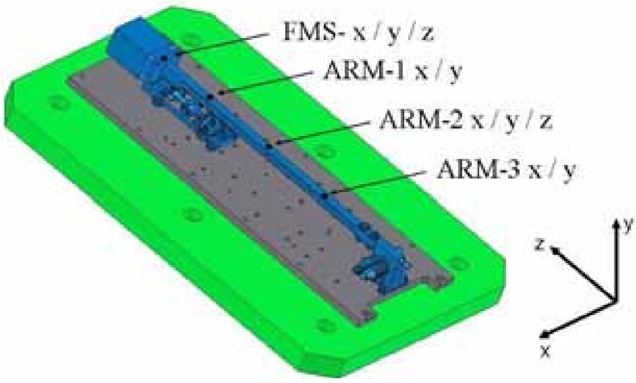


Figure 9 – Positions for accelerometers

Excitation conditions are shown in Tables 1 – 4.

Table 1 – Conditions for pre/ post-low-level random vibration

Direction of vibration	Frequency band(Hz)	PSD level(G^2/Hz)	*RMS (Grms)
x/y/z	20~2000	0.0001263	1.4
Vibration testing for 60sec x/y/z- axis			

*RMS: Root Mean Square Value

Table 2 – Conditions for sinusoidal excitation

Condition of vibration	Direction of vibration	Frequency band(Hz)	Vibration level (G)
Qualification test	x/y	5~100	24
	z	5~100	24
Sweep speed 2out/min x/y/z-axis ; a round trip			

Table 3 – Conditions for random excitation in y direction

Frequency (Hz)	PSD(G^2/Hz)	Grms (G)
20.00	0.0050	*
40.00	2.0000	2.88
50.00	2.0000	5.32
70.00	0.0400	6.12
120.00	0.0400	6.28
300.00	0.6000	9.15
600.00	0.6000	16.24
1000.00	0.0500	18.55
20000.00	0.0500	19.85
Vibration testing for 120sec in y- axis		

Table 4 – Conditions for random excitation in x/ z direction

Frequency (Hz)	PSD(G^2/Hz)	Grms (G)
20.00	0.0050	*
40.00	0.8000	1.96
50.00	0.8000	3.44
70.00	0.1000	4.27
120.00	0.1000	4.82
180.00	4.0000	9.66
220.00	4.0000	15.92
260.00	0.5000	17.86
320.00	0.5000	18.68
800.00	0.0200	20.15
2000.00	0.0200	20.74
Vibration testing for 120sec in x/z- axis		

Now let us discuss the results of vibration testing with the boom EM accommodated with two lock-pins. It was found in case of excitation in *x*-direction that the boom BBM had a trouble in the dummy mass and it was subjected to a violent rotational motion around the single lock-pin (see Figure 5). Therefore the test with excitation in *x*-direction was conducted first to check the effect of two lock-pins on the motion of the dummy mass. 10 accelerometers were fixed on the boom. However, only four accelerometers on CH1, 3, 6 and 8, as shown in Figure 10, are responsible to response in *x*-direction. Eigen-frequencies observed in the testing with excitation in *x*-direction are summarized in Table 5.

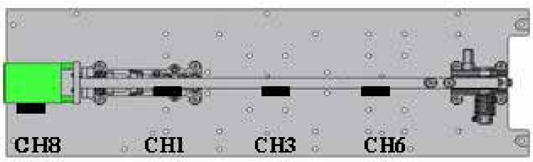
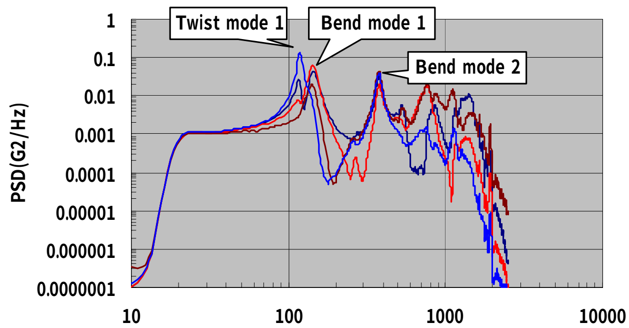


Figure 10 – Positions of accelerometers for response in x-direction

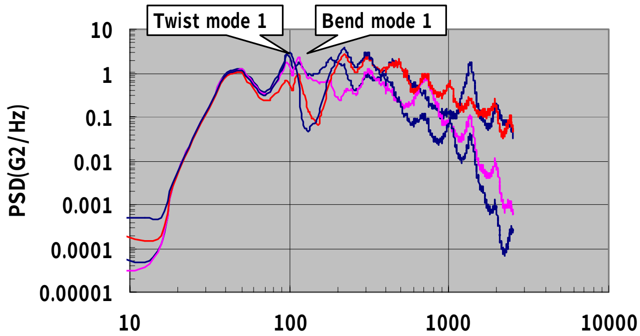
Table 5 – Eigen-frequencies observed in case of excitation in x-direction

	Twist mode 1 (Hz)	Bend mode 1 (Hz)	Bend mode 2 (Hz)
Pre-random vibration	118.7	143.7	378.1
First random excitation	100.0	115.6	330
Second random excitation	96.87	112.5	330
Post-random vibration	103.1	156.3	375.0

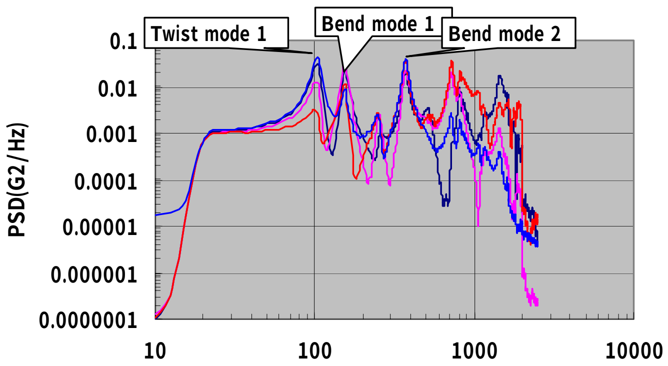
Power spectral density (PSD) in three excitation conditions is shown in Figures 11, 12 and 13.



Frequency (Hz)
Figure 11



Frequency (Hz)
Figure 12



Frequency (Hz)
Figure 13

Figure 11 – PSD in case of pre-low-level random vibration in x direction

Figure 12 – PSD in case of random excitation in x direction

Figure 13 – PSD in case of post-low-level random vibration in x direction

Survey of Table 5 tells that there was observed a considerable reduction in eigen-frequency of twisting mode between the pre-random vibration and post-random vibration. This was attributable to possibly increased gaps in components after the testing. Mode shapes obtained from the response in *x*-direction are depicted in Figure 14.

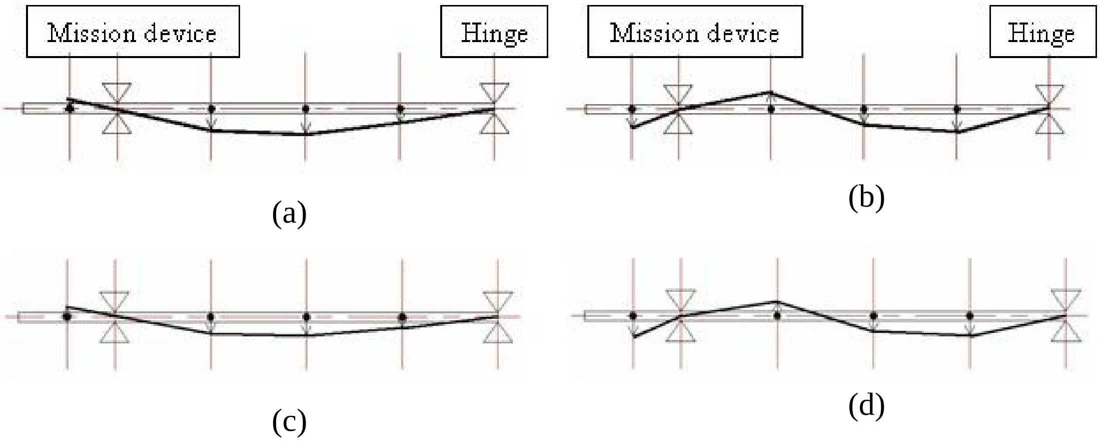


Figure 14 – Mode shapes obtained by vibration test with excitation in x direction

(a) First bending mode in case of pre-random vibration testing
(b) Second bending mode in case of pre-random vibration testing
(c) First bending mode in case of post-random vibration testing
(d) Second bending mode in case of post-random vibration testing

The maximum accelerations observed in case of sinusoidal excitation in x direction are summarized in Table 6. It is found that a very violent acceleration took place at CH8, that is at the mission device. These data might imply a weak stiffness of the present boom system.

Table 6 – The maximum accelerations in x-direction

CH8		CH1		CH3		CH6	
Frequency(Hz)	Acceleration(G)	Fre.(Hz)	Accel.(G)	Fre.(Hz)	Accel.(G)	Fre.(Hz)	Accel.(G)
100.0	81.9	100.0	24.3	100.0	64.8	100.0	14.9

CONCLUDING REMARKS

Development of a pin-puller for a boom to be installed in a 50 kg-class micro-satellite has been reported in this paper. A simple spring-string type pin-puller was proposed and developed. The boom with a pin-puller BBM was subjected to vibration testing to find that a single lock-pin was insufficient for launch-locking the boom. Redesigned pin-puller is two-pin type to suppress rotation motion of a mission device. Its vibration testing has yielded a proto-type model (PM) of pin-puller for the boom PM.

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