DEVELOPMENT STATUS OF LOW-SHOCK PAYLOAD SEPARATION MECHANISM FOR H-IIA LAUNCH VEHICLE

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ABSTRACT

This paper presents the design, analysis and test results of the low-shock payload separation mechanism for the H-IIA launch vehicle. The mechanism is based on a simple and reliable four-bar linkage, which makes the release speed of the marman clamp band tension lower than the current system.
The adequacy of the principle for low-shock mechanism was evaluated by some simulations and results of fundamental tests. Then, we established the reliability design model of this mechanism, and the adequacy of this model was evaluated by elemental tests.
Finally, we conducted the system separation tests using the payload adapter to which the mechanism was assembled, to confirm that the actual separation shock level satisfied our target.

1. INTRODUCTION

The H-IIA upgrade project [1] aims mainly at improving the vehicle's mission capabilities and payload environmental conditions, as shown in Fig. 1. Under this project, to reduce the payload shock environment is considered to be especially important, because the current shock environment of H-IIA is much higher than other competitive launchers of the world.
So the development of low-shock payload separation mechanism was started to make the payload shock environment lower than 1000 G which was comparable to the state-of-the-art.

The current payload shock environment of H-IIA is specified as 3000 G or 4100 G dependent on the adapter types, which uses conventional clamp-band system.
The clamp-band systems have been widely used in almost all the launch vehicle in the world for securing spacecraft inside the payload fairing, and have been used for separation of spacecraft or satellites from the launch vehicles. These systems are very simple and offer a reliable operation, and they have extensive flight heritage. However, clamp-band systems are typically released by pyrotechnic devices such as bolt cutters or separation nuts that holds the clamp band in its preloaded state for the launch phase. This system has high strength and stiffness when clamped and releases quickly when operated. As a result, considerable high shock is generated after separation that could have a significant effect on the equipment located nearby.
Therefore, we have developed the new clamp-band release mechanism which could reduce the shock generated by separation. This paper describes the design and verification test results of the newly developed clamp-band release mechanism.

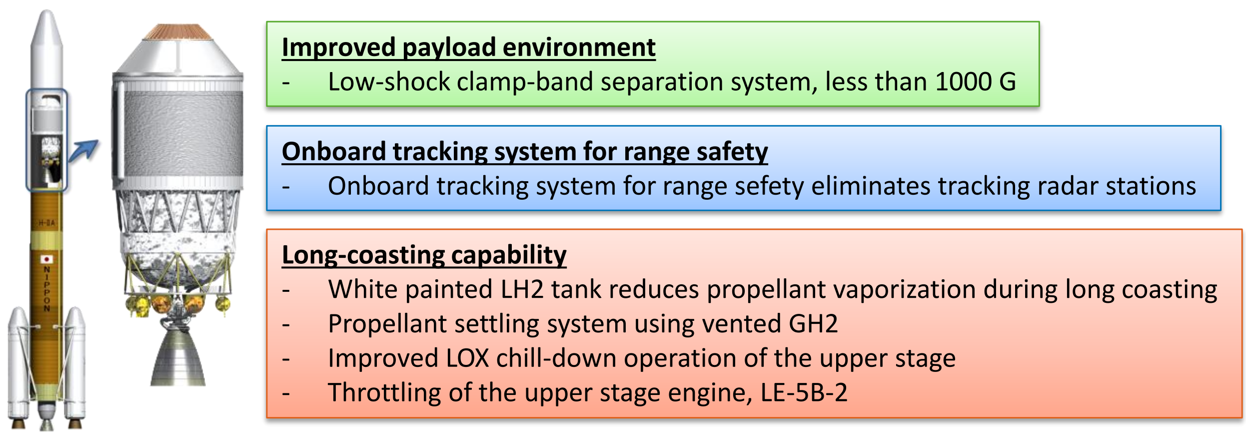

Figure 1. The overview of H-IIA upgrade.

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2. BASIC PRINCIPLE

The clamp band has a circumferential length shorter than that of the interface ring of spacecraft and the launch vehicle adapter, therefore the clamp band can only be installed in tension loading. Usually a release mechanism containing pyrotechnic devices such as bolt cutter is used to release this tension of the band.

Generally, it is said that the largest source of separation shock is the rapid release of stored strain energy. The preloaded tension of the band results in strain energy stored in the sections of the structure in the load path. And bolt cutters or separation nuts release this strain energy in a very short time, typically less than 0.1 milliseconds. This rapid release of strain energy leads to significant high shock level.

Therefore, our basic principle for shock reduction is to reduce the speed of release of the band tension, to make the release of strain energy of the structure much slower.

In order to decide the target time of tension release, we conducted simple simulations to confirm the relationship between the tension release time and the shock level generated. We assumed three types of tension release curve; sudden release, cosine curve release, and linear release, as shown in Fig. 2. The release time, described as ε in Fig. 2, was changed from 0.25 milliseconds to 5 milliseconds, and we simulated the shock levels generated by the release of the tension. The result is shown in Fig. 3. From this result, we could find out that the linear release model was the most effective for shock reduction but the cosine curve release model was also effective compared with the sudden release model. And, in both cosine curve model and linear models, the shock level was to be reduced under 1000 G when the tension release time was longer than 2 milliseconds.

From this simulation result, we decided the target time of the tension release as more than 2 milliseconds. And the tension release model could be acceptable either of cosine curve or linear model.

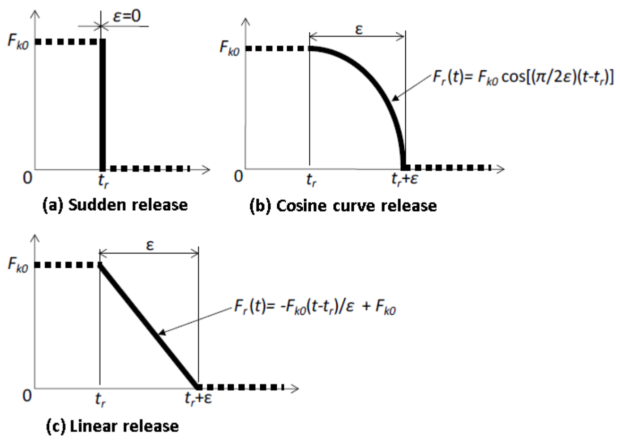

Figure 2. Three types of tension release model.

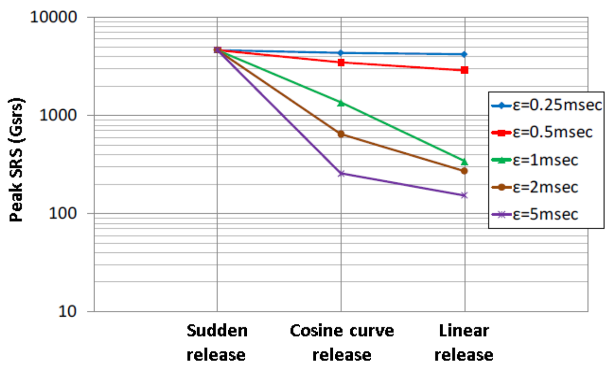

Figure 3. The simulation results.

3. DESIGN DESCRIPTION

Aiming for this design target, we designed the new release mechanism of the clamp band system. The overview of the payload adapter with new release mechanism is shown in Fig. 4. One release mechanism is applied to the clamp band system, and opposite side of the band is jointed by only bolt and nut for tension loading.

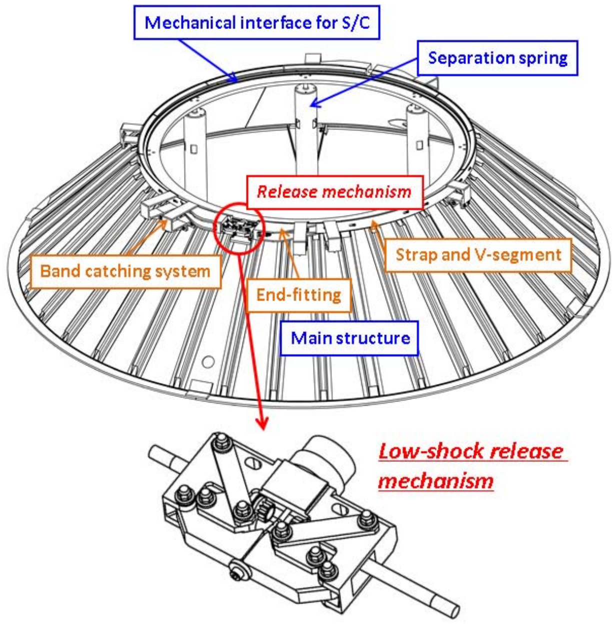

Figure 4. The overview of a payload adapter.

The release mechanism is based on simple four-bar linkage mechanism which consists of “Lever”, “Support”, “Link”, and “Base”. The schematic model of this mechanism as a four-bar linkage is shown in Fig. 5. The “Base” is the frame of the linkage which is fixed to the adapter structure. The input force is applied at the “Support” by the tension of the clamp band through the bolt, so the “Support” is the driver of the linkage. The

“Link” has the roll of the connecting rod of the linkage, and the “Lever” is the follower of the linkage to output the release force of the clamp band system.

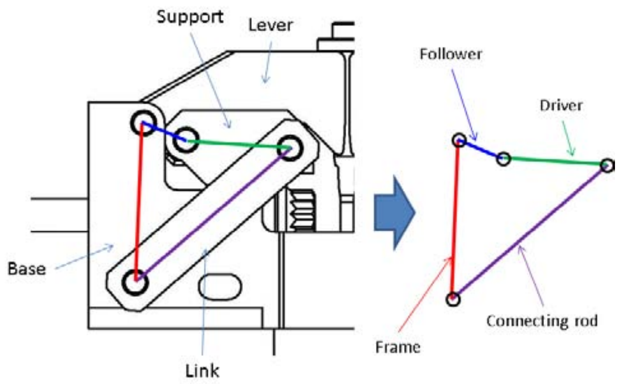

Figure 5. Schematic model as four-bar linkage.

Before the release, the tension of the clamp band is strictly kept by “Support” and “Base” by grasping the bolt head with washer. The motion of the linkage is restricted by release rod and actuation device, as shown in Fig. 6.

For the actuation device of this mechanism, we adopted the SSD 9100 supplied by NEA Electronics Inc., which is the flight-proven, highly reliable non-explosive actuation device.

Then, once this actuation device unlocks the release rod, the linkage mechanism is actuated by the tension of the band. The “Lever” is released from the restriction of the release rod to allow the linkage mechanism to move, then “Support” goes upward, and release the bolt head, as shown in Fig. 7.

Finally the bolt can get out of the mechanism and the tension of the band is released.

Based on this concept, we designed the size and shapes of each component of the mechanism.

Simply, the larger and heavier each component is, the slower the motion of the linkage becomes. However, large and heavy mechanism is not suitable for the application to the payload adapter. So we conducted some mechanism analysis to decide the dimensions of each component, and finally decided them as to satisfy the requirement of the band tension release time of more than 2 milliseconds.

To verify that the design of the mechanism satisfied the requirement, we measured the band tension release behaviour by the load cell installed to the bolt in the actual test. The result is shown in Fig. 8.

The actual tension release time was about 3 milliseconds in nearly cosine curve, so the design of the release mechanism was confirmed to satisfy the primary design requirement.

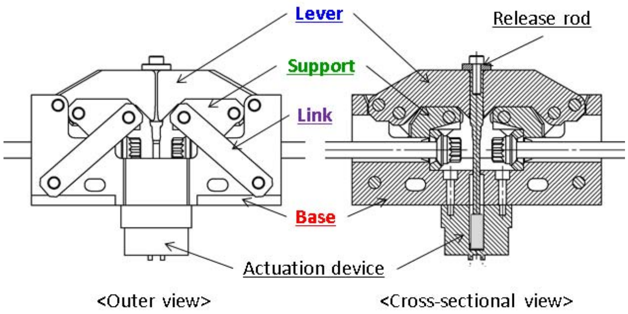

Figure 6. Before the release.

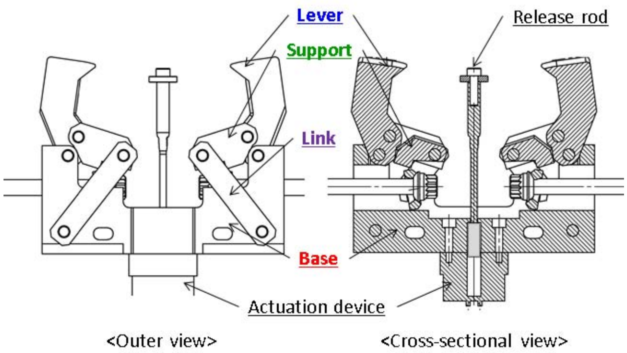

Figure 7. After the release.

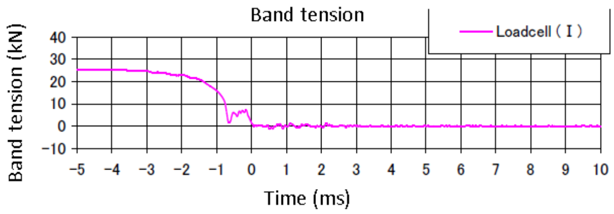

Figure 8. Band tension behaviour of release.

4. RELIABILITY MODEL

The primary requirement for the release mechanism is the reliability of actuation. In this development, not only the shock reduction but also keeping the reliability as high as the current system is so much important.

In this point of view, we had to establish the reliability model for this new release mechanism to assure that the reliability is higher than the current system.

Naturally, this release mechanism is in very simple and reliable design because the motion of the four-bar linkage is physically predictable. The force required to drive this mechanism is designed to much lower than the tension applied within usual marman clamp band systems. We set the reliability model by the relationship between the band tension during flight and the force required to actuate the mechanism, and design requirement is decided to have more than three times margin within the relation of them, as shown in Fig. 9.

Throughout the development tests of this mechanism, the distribution of the force required to actuate the mechanism was measured under various test conditions including;

- the effect of manufacturing tolerance
- the effect of the variation of friction characteristics of components
- the effect of operational environment
- the effect of loading conditions

The design and manufacturing parameters sensitive for the actuation force were selected exhaustively by means of FTA and FMEA, and the sensitivity of each parameter was examined by a number of elemental tests.

Finally we could define the distribution model of the force required to actuate the mechanism, based on more than 700 test data.

On the other hand, the band tension during flight is considered with the effect of thermal and mechanical environment, aging effect, and tolerance of tension loading. The quantitative effect of each parameter was verified in the past test results individually.

Throughout these activities, we confirmed the reliability of actuation of the mechanism is equivalent to the current bolt cutter system.

Add to that, the mechanism has redundant two linkages. Actuation of either one of them allows the clamp band to get released.

This reliability design has been verified through over 100 separation tests covering all the expected operational conditions, with no failure of actuation up to now.

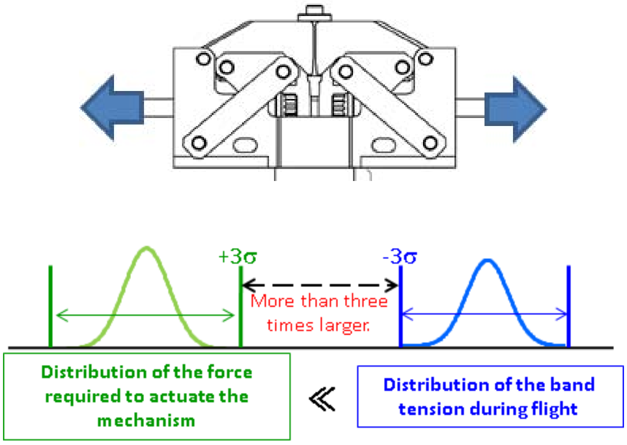

Figure 9. The reliability model of the mechanism.

5. TEST RESULTS

Finally the new release mechanism was assembled to the payload adapter of H-IIA and verified that all the required properties were achieved.

The actual actuation sequence was evaluated through the separation tests by band tension data like Fig. 8 and observation of high-speed video system. The example of the actual sequence of the motion is shown in Fig. 10. We could verify that the mechanism was actuated properly as expected by design analysis.

Throughout a number of separation tests under various conditions, the shock level generated by separation is confirmed under 1000 G. One of the typical shock data on the upper limit of the tension of the band is shown in Fig. 11. In this SRS result, there are no apparent knee point around 1000 Hz, which is the peak frequency in the current bolt cutter system. So we could confirm that the reduction of tension release speed was highly effective for reducing the shock level.

As for the qualification test of this system, we have conducted the full verification for the design requirement.

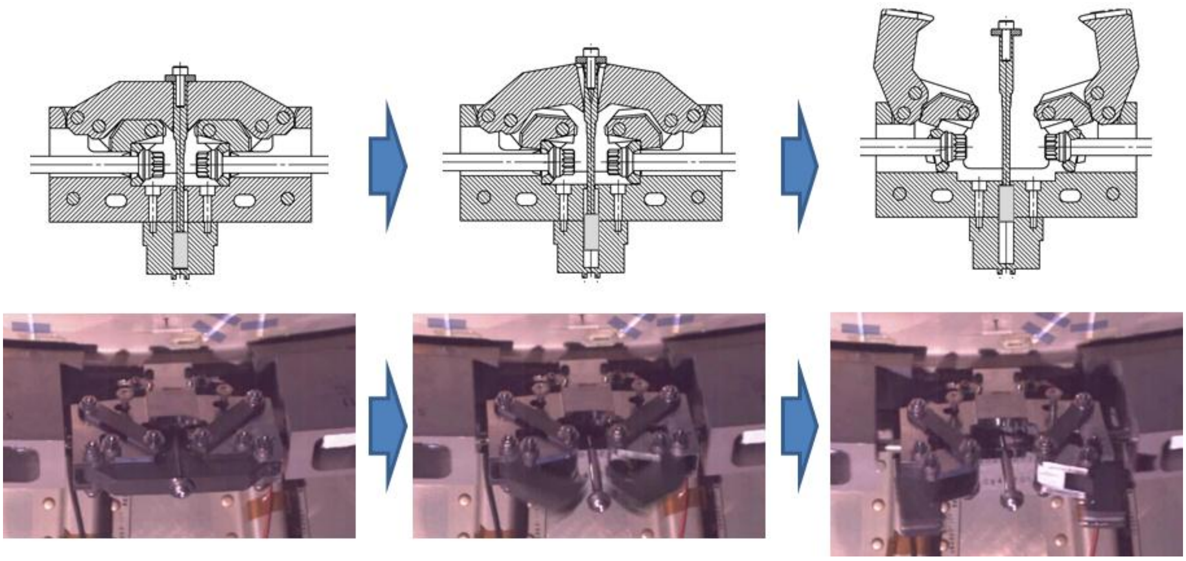

Figure 10. The actuation sequence observed by high-speed video system.

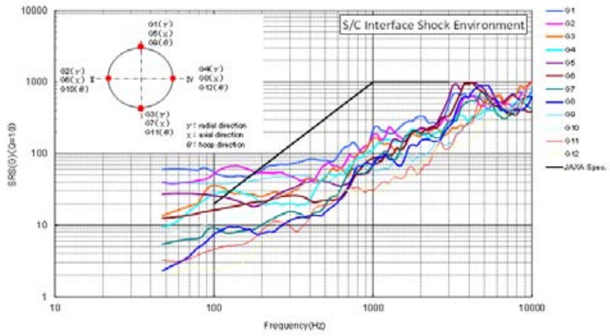

Figure 11. Typical shock data.

Strength and stiffness of clamp band system including this new release mechanism were verified by the strength test. We conducted QT level and over-loaded level tests to assure the proper structural margins.
Regarding the reliability, the reliability design model was verified in the reliability tests as previously described. Total system reliability of separation was verified by the system separation test of payload adapter, in the variety of conditions which fully covered the expected flight conditions. Over 100 separation tests were already conducted.
Separation dynamics; the clamp band behaviour, angle tip-off rate, clearance to the usable volume of spacecraft, and so on; was verified simultaneously in the system separation tests of payload adapter.
Up to now, all the design verification and qualification tests have been conducted successfully, and will be completed this year.

6. SUMMARY AND CONCLUSION

In this paper, the development status of new low-shock payload separation mechanism for H-IIA launch vehicle was described.

The mechanism was based on a simple and reliable four-bar linkage, which made the release speed of the marman clamp band tension lower than current system.
The adequacy of the principle for low-shock mechanism was evaluated by some simulations and results of fundamental tests.
The reliability was verified through the development tests based on the reliability design model that we established.
The separation shock generated by separation was confirmed to be under 1000 G which satisfied out target level. And other design requirements as a payload adapter system have been verified successfully thorough the qualification test series up to now.
Now we are conducting some tests in the final phase of this development, aiming at the first application in 2015, to bring the H-IIA upgrade version with this low-shock payload separation mechanism to market as quickly as possible.

7. REFERENCES

[1] http://www.jaxa.jp/pr/brochure/pdf/01/rocket08.pdf