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Motion Analysis of Band Release System

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Abstract—Stage separations are critical events with multistage satellite launch vehicle. Parts of satellite and spacecraft must be separated during flights that are no longer needed and separations must occur at the correct times of flight and with clean separation. There must be no contact between the separating bodies, no shock loads, and no harmful debris. These can produce attitude errors, damage the structure and critical equipment, and cause mission failure. In this paper an extended study of motion analysis has been carried out for a Band Release System. Modal analysis of the band and the wedge block has been carried out to extract the modal frequencies of the band and to see the behaviour of the band. Motion analysis of the whole system has been carried out in ADAMS[Automatic Dynamic Analysis of Mechanical System]with an aim to see how reliable is the system in the performance of clean separation. Motion analysis of the system has been carried out to asses the displacement, velocity and acceleration of the wedge block and band after the actuation of the pyro-thruster.

Keywords— ***Marman band, Band Release System.***

I. INTRODUCTION

Marman Band assemblies provide the connection mechanism for the structure between two adjoining main systems. The band systems have been widely used in the aerospace industry for securing payloads inside the launch vehicle payload fairing and have been used for separation of spacecraft or satellites from the launch vehicles. These systems offer excellent structural properties; very simple operation and extensive flight history. However, band systems are typically released by operation of pyrotechnic devices such as bolt cutters or separation nuts that holds the clamp band in its preloaded state for the launch phase of the mission. 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 deleterious effect on the structure or equipment located nearby.

II. 2. LITURATURE SURVEY

Zhao-Ye Qin, Shao-ZeYan, Fu-LeiChu [1] has studied in this paper, the dynamic responses of the light vehicle system to the vibration and impact excitations were studied, where the effect of the clamp band joint was taken into account. Firstly, the mathematical model of the axial stiffness of the clamp band joint was derived. In the model, contact and slippage between the components were accommodated. Then the stiffness model was employed to construct the coupling dynamic model for the light vehicle system using the finite element software ANSYS. Finally, modal analysis and response analysis were carried out on the coupling dynamic model to investigate the dynamic characteristics of the light vehicle system; the simulation results were compared with those based on the dynamic model where the launch vehicle and the spacecraft were considered to be fixed together to explore the effect of the clamp band joint on the light vehicle system.

NASA Space Vehicle Design Criteria[5] has discussed that parts of a space vehicle must be separated during flight to jettison stages and components that are no longer needed, to uncover equipment, or to deploy payloads. In this criteria and recommends practices for the design and testing of mechanisms for separating space-vehicle stages, payloads, and pods. The advantages and disadvantages of various separation techniques are presented and the characteristics of typical devices that have been used to effect separation were discussed. The mechanical and structural elements that maintain load-path continuity and accomplish separation are emphasized, rather than the auxiliary devices used to time, energize, interconnect, and monitor separation events. Separation dynamics, the effects of environments and operating conditions, and methods of analysing and testing separation mechanisms were also discussed. The separation of fairings and payload aerodynamic shrouds is a complex subject

David dowen, Scott Christiansen and Orjan Arulf[[7]The clamp band system described by above author reduces shock in two ways: it eliminates shock typically associated with pyrotechnic release devices as well as utilizing a release device that reduces the shock associated with the rapid release of the preload strain energy. Patented Fast Acting Shock-less separation Nut (FASSN) technology is utilized to convert strain energy stored in the system into rotational energy of a flywheel. Additional development of the FASSN device has reduced the size and weight to enable the use of the technology in a medium sized (23 to 60 cm diameter) clamp band system. He has decribed the overall design, performance, and initial test results for the FASSN-based, non-pyrotechnic, low-shock clamp band release system.

III. 3. DESIGN CONCEPT OF BAND RELEASE SYSTEM

Generally, the separation band system used in the aerospace industry consists of four main parts: an upper ring i.e Fore Ring, a launch vehicle adapter including lower ring i.e Aft Ring, wedge block and a clamp band as shown in fig 1. The fore ring is installed on the bottom of the spacecraft adapter permanently and serves as the upper surface of interface plane. On the top of the launch payload adapter, the lower ring is installed and serves as the lower surface of interface plane. The clamp band is manufactured in two identical halves and connected together at their ends by pyrotechnic lock devices. In addition, eight catchers dependent on the ring diameter are fixed to the payload adapter's ring, to guide, catch and park the band within the allowed volume after the band is released. The clamp band has a peripheral length shorter than that of the upper ring and the launch vehicle adapter; therefore the clamp band can only be installed in tension. A release mechanism containing pyrotechnic devices is used to release the band.

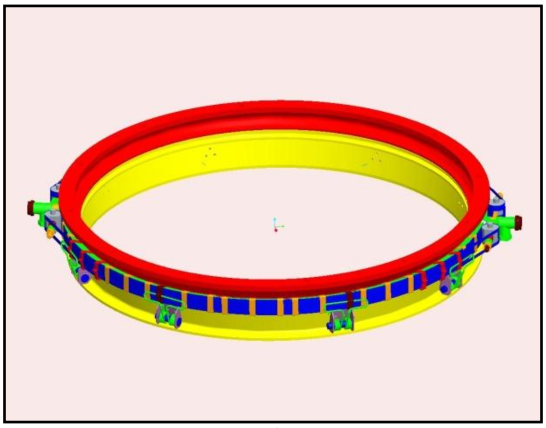


Fig. 1**:** General view of Band Release System

IV. MODAL ANALYSIS

The clamp band is pre-tensioned during assembly and is locked in this state by the piston of the pyro-device. When the pyro-device is actuated the tension in the band is released. Post-release motion of the band would depend on the natural rhythm of the band with the masses (components) attached to it. Therefore for analysis of it's motion, it is necessary, to find the modal frequencies of the band along with wedge blocks and damping spring assembly.

Band and wedge blocks have been considered for this response analysis. Wedge blocks were represented as lumped masses and they were bonded with the band. Only one band and related wedge blocks were considered for the analysis.

4.1 Mesh Generation

The band and wedge block are meshed with hex elements as shown in fig. 2 Node set are created in hypermesh to define contact (Bonded) in Ansys. The wedge blocks are assumed to be lumped mass.
Total number of elements are 51896 and nodes is 77577.
Normal mode analysis with 10 number of mode shapes to be extracted was defined in Ansys.

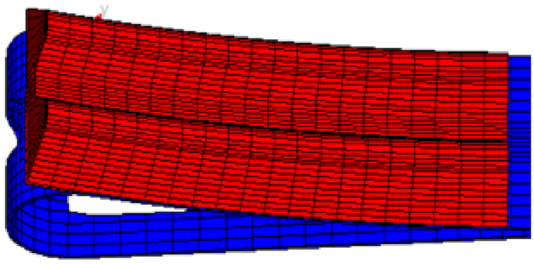


Fig 2**:** Meshed model of band and wedge block

4.2 Results and Discussion

Various mode shapes of band and wedge blocks were analyised. Mode shape with frequency are shown in table

Table 1: Mode shape and Time/Frequency for combine band and wedge block

Mode Shapes	1	2	3	4	5	6	7	8	9	10
Modal Frequency in cycle/sec	0	0	0.007	0.559	0.881	1.362	6.221	18.871	34.877	59.783

frequency of the modes 7 to 10 modes is greater than zero as shown in figures 3.

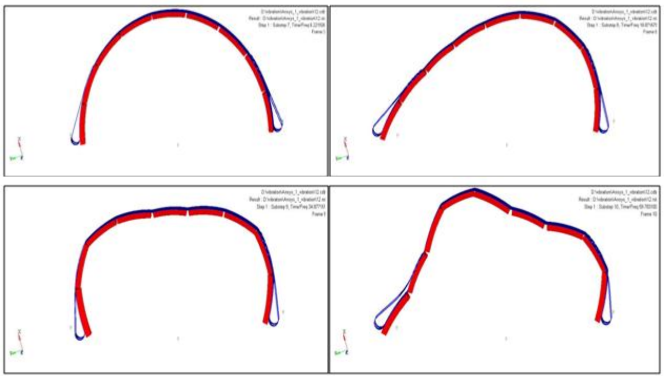


Fig. 3: Mode Shapes of band with wedge block

These mode shapes represents the possible shapes the band will assume at various instance of it's motion after release. It is therefore necessary to carryout motion analysis of the band at these resonant modes to understand the behaviour of the Band Release System (BRS)

V. MOTION ANALYSIS OF BRS

Motion analysis of the Band Release System has been carried out in ADAMS, to see if there is a complete seperation of wedge block from the Fore ring and Aft ring joint after the band has been released

5.1 Analytical Method

BRS is essentially a clamp band, that is a ring-shaped tension clamp. Analytical method for the determination of displacement, velocity and acceleration of band and wedge block assembly using strain energy principle-a simplistic solution. Due to the application of tensile load of 1.17tones at the roller end of band, strain energy is stored in the band. When this load of 1.17 tones is released suddenly, the strain energy stored in the band and wedge block gets converted into kinetic energy.

5.1.1 Band

Calculated stain energy of the band

i.e U_b =17775.2 N-mm

Assuming 100% conversion efficiency, Strain energy in the Band assembly before release is equal to Maximum kinetic energy in the band after release

With this assumption calculated velocity of the band is,

$$v = 74.18\, m/s$$

Frequency of the band is,

$$f_{nb} = 11.57\, Hz$$

Time period,

$$T = \frac{1}{f_{nb}} = 0.085\, sec$$

Calculated acceleration of the band, $a = 872\, m/s^2$

Calculated displacement is, $x = 30.71\, mm$

5.1 .2 Combined Effect of Wedge Block and Band

Total strain energy in band(U_b) and wedge blocks (U_w)is

$$U_{tot} = U_b + U_w = 28840.5\, N - mm$$

Assuming 100% conversion efficiency, Strain energy in the Band assembly before release is equal to Maximum kinetic energy in the band after release

$$28840.5 = \frac{1}{2}.m.v^2$$

$$v^2 = \frac{2}{6.4603} \times 28840.5$$

$$v = 94.49\, m/s$$

Neglecting energy absorbed by the torsional springs

This is the maximum velocity attainable by the assembly before the reverse motion due to the torsion spring begins. Assuming that this assembly will vibrate without any external damping and reverse motion will start only after the

completion of one cycle so it is assumed that the assembly will attain maximum velocity after completion of the ¼ th cycle or after first time period(T/4)
All wedge blocks are in series with band so the equivalent stiffness of the assembly is,

$$\frac{1}{K_{eq}} = \frac{1}{K_{eqw}} + \frac{1}{K_b}$$

$$K_{eq} = 3624.24\, N - mm$$

$$\omega_n = \left(\frac{K_{eq}}{m}\right)^{\frac{1}{2}} = \left(\frac{3624.24}{6.4603}\right)^{\frac{1}{2}} = 23.68\, rad/sec$$

$$f_n = \frac{\omega_n}{2\pi} = \frac{23.68}{2\pi} = 3.76\, Hz$$

Time period,

$$T = \frac{1}{f_n} = 0.2653\, sec$$

Calculated Acceleration of wedge block and band is, $a = 356.17\, m/s^2$
Calculated displacement, $x = 25.06\, mm$

5.2 Assumption of Band Release System.

- Band release mechanism is symmetric so we can do analysis of half model and assume it that the other half also behaves the same.
- The contact deformation between the of the wedge blocks and the strain energy released from the wedge blocks is neglected for this analysis.
- Only the inertia effect of the wedge block is being taken into consideration
- The effect of the double torsional helical spring is being considered for simulating the damping effect.

5.3 Flex-body Mesh Generation of Band

Flex-body of the band is taken from the modal analysis model as shown in fig. 2
Total number of elements: 3840
Band was meshed in the Hypermesh and deck was prepared to create the MNF(Model Neutral File) is done in Patran and it was exported as .bdf and Nastran as the solver was used. The 10 mode shapes i.e natural frequency of the band was extracted in the MNF file and they are listed below.

Table 2: Mode shape and Frequency for band

Mode Shapes	1	2	3	4	5	6	7	8	9	10
Frequency in cycle/sec	0.041	0.045	0.048	0.063	0.073	0.12	81.24	271.73	453.48	628.32

The motion analysis from seventh to tenth mode shapes has been considered.

5.4 Modeling in ADAMS

1. Aft ring is converted to ground.
2. As there is no relative motion in between the bracket and spring guide they have been merged into single part (so that the numbers of iterations are reduced).
3. Clip type-I, II, III are merged to respective wedge block Type-I or II as there will be no relative motion in between them.
4. The created Single_Belt.mnf file is replaced with flex body band.
5. Material properties are assigned to each of the parts. As the material properties are assigned, automatically the '.cm' markers are created for each part.
6. Fore ring is fixed to the aft ring with help of fixed joint.
7. Markers are created on each spring guide center with the help of marker from Adams.
8. Torsional spring is created between the spring guide and the double torsional spring with the stiffness of 164 N/mm on each spring guide 'marker'.
9. Revolute joint is defined between the each spring guide and the spring on created 'cm' marker.
10. 3D contact has been defined between the following parts , Spring and the band ,Spring and clip type- II and III, Each wedge block and band and between different wedge blocks, Wedge block and aft ring, Wedge block and for ring, Four spring and the flex body band.
11. Markers are defined at each wedge block inner circumference as shown in the fig 4 and Displacement, Velocity and acceleration is measured with respect to defined each markers wedge block.

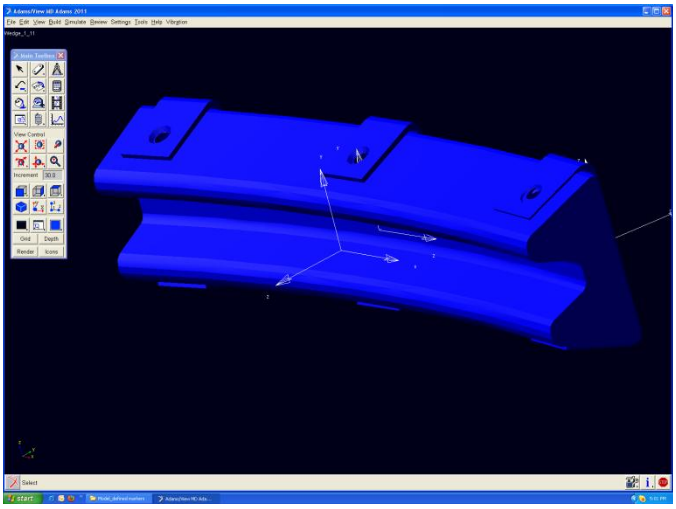
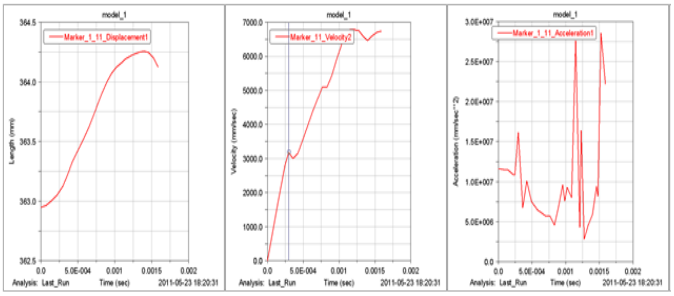


Fig 4: Wedge block from Adams/ View showing marker position

5.5 Graphical Representation of Wedge Blocks after Release



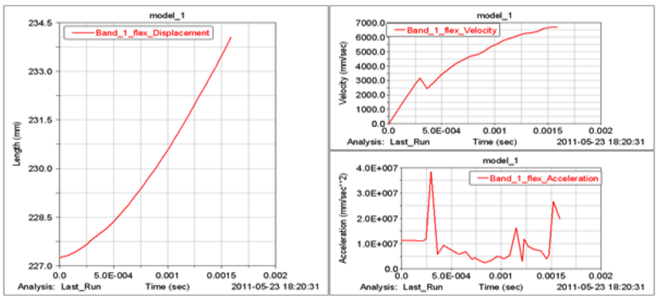
Graph 1. Displacement, Velocity and Acceleration of wedge block 1_11 for mode shape 7

From the Graph1 it is observed that the maximum displacement for wedge block 1_11 is 364.26 mm i.e it displaces 1.3mm from the marker specified at the tip of the wedge block. From the Graph 2 the maximum velocity for the wedge block 1_11 is 6791.39 mm/sec.The maximum acceleration for wedge block 1_11 is 2.7609E7 mm/sec^2.

Table 3: Measure of displacement, velocity and acceleration for mode shape no 7

Part Name	Displacement(Max) (mm)	Velocity(Max) (mm/sec)	Acceleration(Max) (mm/sec^2)
Wedge_1_11	1.3	6791.39	2.7609E7
Wedge_2_3	3.3	7176.10	3.4701E7
Wedge_1_12	5.3	5874.28	5.2717E7
Wedge_1_13	6.2	7519.83	1.0942E7
Wedge_1_14	6.4	7345.79	8.7399E7
Wedge_1_15	6.7	7.2067E4	2.3037E7
Wedge_1_16	4.6	5926.52	1.0768E7
Wedge_2_4	2.6	6126.32	3.2883E7
Wedge_1_17	0.4	5514.08	3.1737E7

5.6 Graphical Representation of Band



Graph 2. Displacement, Velocity and Acceleration of band for mode shape 7

From the above Graph 32 it was observed that the highest displacement is 17.62 mm at 0.0083 sec, Velocity is 23166.73 mm/sec at 0.0025sec and acceleration is 1.5723E10 mm/sec^2 at 0.0054 sec.
Similarly, simulation has been run for other frequencies i.e. 271.73, 453.48 and 628.32 cycles/sec and displacement, velocity and acceleration has been plotted.

VI. RESULT AND DISCUSSION

One of the main criteria for evaluation of the reliability of the Band Release System, is **clean separation**, between two stages,**each time** the pyro device is operated. This works out to there being a complete seperation of wedge block from the Fore ring and Aft ring joint after the band has been released. Therefore the modelhas been simulated for different mode shapes of the band to evaluate the same.

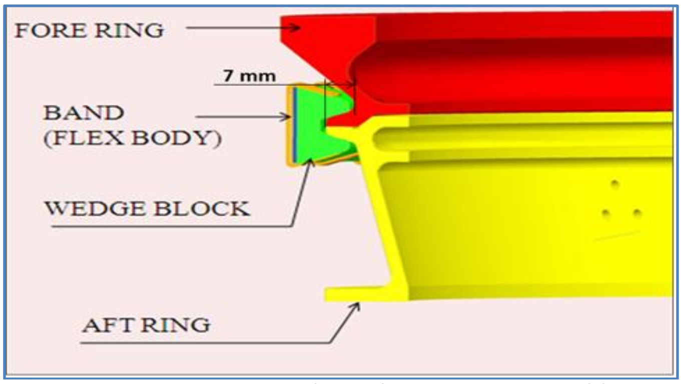


Fig 5: Minimum displacement of band for clean separation of fore ring

Functioning reliablity assesment based on clean separation function has been carried out by studying the dynamic analysis results for each of the modal frequencies. It appears that there is a possibility of snagging of the wedge blocks with the FR in many cases.

Insufficient displacement leading to release failure/snagging of wedge block with FR has been listed below table 4.

Table 4 Insufficient displacement leading to release failure/snagging of wedge block with FR and their specific modal frequencies (cases shown in red).

Wedge Block No	Modal Mode shape no7 (8.24Hz)	Modal Mode shape no8 (271.73Hz)	Modal Mode shape no9 (453.48Hz)	Modal Mode shape no10 (628.32Hz)
1_11	1.3	0.8	1.1	8.2
2_3	3.3	1.6	5.8	8.2
1_12	5.3	2.9	12.1	13.7
1_13	6.2	5.1	14.5	14.6
1_14	6.4	6.5	15.7	13.9
1_15	6.7	7.1	16.1	11.1
1_16	4.6	6.9	14.4	7.6
2_4	2.6	5.2	10.9	1.3
1_17	0.4	5.6	5.9	0.9

However during the above simulation it was seen that the geometric defination between the band and both the end clips got disrupted during the relative motion of the band. The simulation terminated itself at that point.
The simulation has been rerun for mode shape number 10 by modifying the geometry by removal of end clips from the assembly.

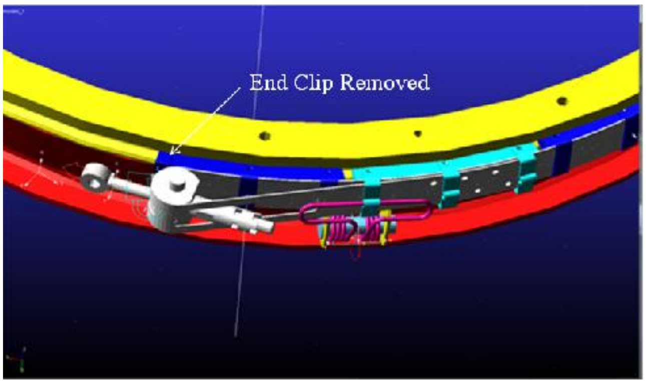


Fig 6: Geometry modification

The maximum displacement with respect to time is given in the tables below.

Table 5: Maximum displacement of wedge blocks with respect to time

Wedge Block No	1_11	2_3	1_12	1_13	1_14	1_15	1_16	2_4	1_17
Time in sec	0.32	0.42	0.42	1	0.32	0.92	0.42	0.42	0.43
Max Displ. In mm	2.4	3.4	5.9	5.1	5.4	5.6	5.7	4.3	1.7

Maximum radial displacement of the wedge block is seen to be less than the minimum displacement required for the tip of wedge blocks to clear the FR and Hence the functioning reliability in the above case is not met by the design.

VII. CONCLUSIONS

1. Motion analysis of the whole system has been carried out with an aim to see how reliable is the system in the performance of clean separation.
2. Motion analysis has been carried out for the fourindependent modal frequencies, viz.81.24, 271.73, 453.48 and 628.32 cycles/sec
3. The maximum displacement values obtained from the results of the simulation when compared with the minimum displacementrequired for clean release indicate **Release Failure due to Snagging of wedge block with FR.**
4. The design of the BRS has to be modified to achieve this essential requirement of **Functionality**.
5. The movement of the wedge blocks needs to be evaluated from the dynamic analysis of the system at the other natural/modal frequencies.

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