Deployment Dynamics and Latch-Up Shock Estimation of Large Antenna Hold Down Mechanism

B. Lakshmi Narayana, B. P. Nagaraj, G. Nagesh & C. D. Sridhara

Abstract

Large aperture deployable mesh reflectors have potential use for satellite communication. These are light weight and flexible. These reflectors need to be stowed to a compact volume and held to the spacecraft deck through hold down and release mechanism (HDRM) at multiple locations during launch due to space constraints in launch vehicle and also to meet the necessary frequency requirement. HDRM will be released, deployed and latched to the intended position in the orbit. The dynamics and latching of one such HDRM is analysed in this paper. The mechanism consists of two deployable, spring driven circular plates connected by a pre-tensioned bolt. Upon deployment these circular plates latch into their intended position. The flexibility of the circular plate is modelled during its deployment. The velocity of the deploying plates is estimated and a transient dynamic analysis is carried out, imposing the velocity as initial condition to estimate the latching forces and moments. The latching loads form input for the design of HDRM mechanism.

Keywords: Dynamics, Deployment Mechanism, Transient dynamics, Latching and Shock

1 Introduction

Large deployable mesh reflectors that are automatically unfurlable have been pursued for their potential use for large aperture, lightweight antenna for satellite communication. These kinds of reflectors are larger than the size of the host spacecraft and kept stowed for launch and deployed in orbit. Due to its large size they are held onto the spacecraft at multiple locations through HDRM during launch. This is required to meet the structural/frequency requirements and to protect them against the inertia forces due to launch and from manoeuvres for orbit rising. The

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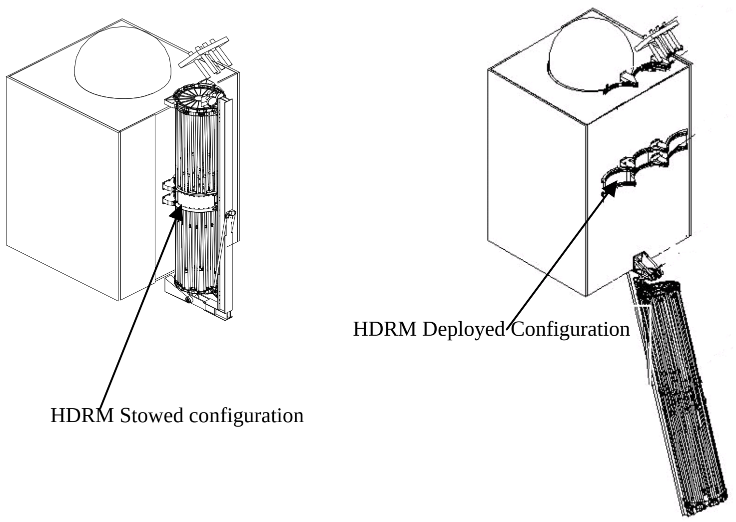
HDRM will be released, deployed and latched to the intended position in the orbit. Any malfunction of the mechanism will cripple the satellite mission and may also result in total loss of satellite. Hence the HDRM has to be analysed to ensure positive release of the mechanism, proper deployment and final latching.

The deployment dynamics of spacecraft appendages like solar array consisting of yoke and three panel were studied [1] by Lagrange's method. This study was extended to *n* panel solar array by matrix approach [2]. The authors have considered damper and air drag effects. In the above formulations panels were assumed to be rigid. The deployment dynamics of two flexible links with revolute joints undergoing locking was studied [3]. The flexibility was modeled by finite element method and locking was modeled by momentum balance method. The theory was validated by experiments. The authors studied in [4] the energy transfer for each stage of locking. In [5] the link flexibility was modeled by Timoshenko beam theory and the simulation results were compared with the experimental results of [3]. The latch up moment was estimated for the single solar panel by transient analysis and energy method [6]. In the *transient analysis*, the spacecraft appendage is considered rigid till the latch up. The velocity distribution of the satellite appendage is triangular and is obtained from the rigid body dynamics using ADAMS. This latch up velocity is taken as initial condition for transient dynamic analysis to estimate the latch up moment at inters panel hinges. The *energy method* is based on the assumption that the latch up kinetic energy is absorbed by the deployed solar array in the form of strain energy. The loading distribution is assumed triangular. The magnitude of loading is the product of equivalent angular acceleration, mass per unit length of appendage and distance along the appendage. The strain energy of the deployed array is calculated for unit angular acceleration. This strain energy is scaled to latch up kinetic energy to obtain equivalent angular acceleration. The deployment of dynamics of solar array considering the flexibility of panels is studied and latching is also modelled by an inbuilt function in ADAMS [7] to estimate the latch-up moment. The latchup force was evaluated through transient dynamic analysis for the Brazilian solar array[8]. Like solar array the antenna used in satellite also latch at the end of deployment. These have one rotational degree of freedom during deployment unlike solar array which are multi degree of freedom connected by closed control loop. The latch up was modelled for the antenna deployment mechanism by using transient dynamic analysis by considering the flexibility of hinge mechanism [9]. The latch up was modelled by both energy and transient analysis for a large antenna with damper[10]. In this paper the deployment and latching of a new type of HDRM is presented. The flexibility of the deployable link is modelled. The transient dynamic analysis used by many researchers as described above is adopted to model the HDRM. The paper is organised as follows. Section 2 presents the system description. Modelling for deployment and latching is presented in Section 3. The results and discussions are presented in Section 4. Finally the conclusions are presented.

2 System Description

The large unfurlable reflectors consist of Deployable Truss (DT) (to support the flexible cable net/reflective mesh) and deployment hinge mechanism. In the stowed configuration, the DT is folded along with the cable net and mesh. In order to off load the acceleration loads coming on DT, the DT is supported at pre defined locations by HDRM as shown in Figure 1a. In the orbit prior to the release of DT, the HDRM is deployed as shown in Figure 1b. The HDRM consists of three aluminum rigid circular plates (one rigidly held and two are deployable) as shown in Figure-2. The two deployable circular plates are connected by a pair of pre tensioned bolts and are released by cutting the bolts by a pyro cutter. The energy for the deployment is provided by the torsion springs mounted at the hinges. Upon deployment the circular plates are latched in to their intended position.



a) Antenna Stack Stowed

b) Antenna Stack after Primary Deployment

Figure-1: Large unfurlable antenna

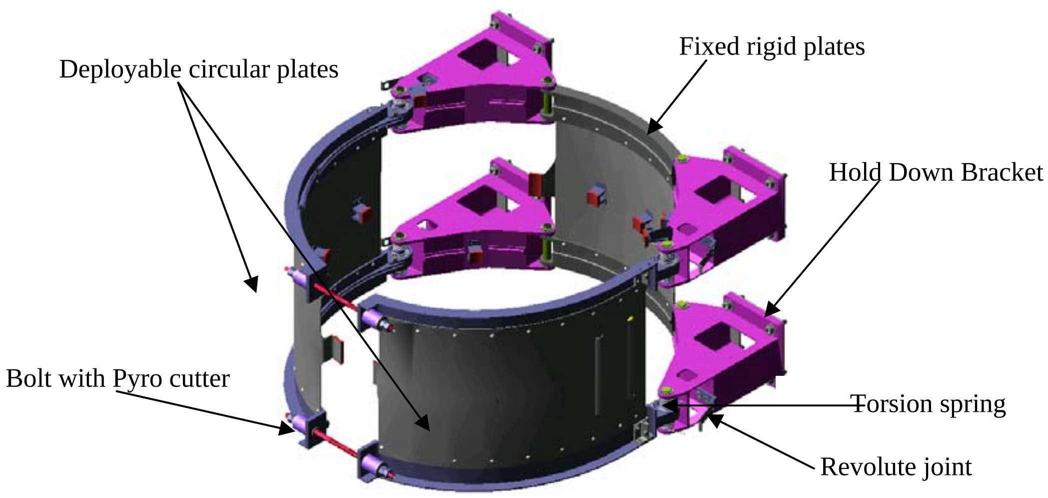


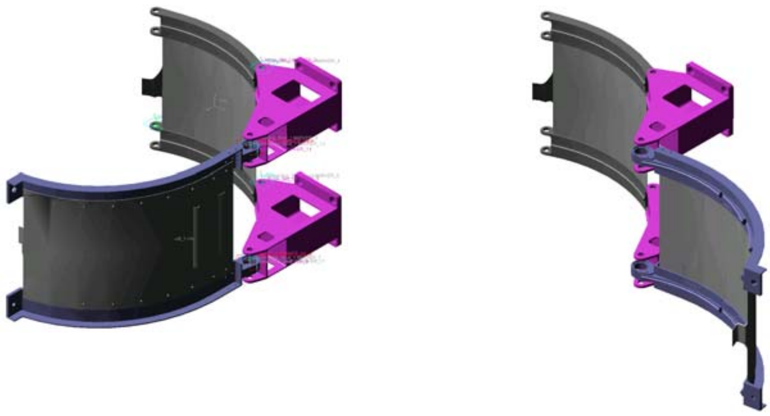
Figure-2:- Mid hold down mechanism

3 Modelling

In this section the modeling approach used for the HDRM is described. The simulation of the deployment of HDRM is carried out to evaluate the velocity with which the plate latches. Using this velocity as initial condition a transient dynamic analysis carried out to simulate the latching of the plate.

3.1 Deployment Simulation

The geometry of the mechanism is modelled in UG-NX and transferred to ADAMS to study the deployment dynamics. The dynamics of the two deployable circular plates will be identical. Hence, the dynamics of one plate is only simulated. The flexibility of the plate is modelled by importing the finite element modal natural file from MSC NASTRAN. Figure 3a presents the stowed configuration of the ADAMS model. The revolute joint is created between the deployable circular plate and hold down bracket. The pre loaded torsion spring is created at the revolute joint. The hold down block is fixed by creating a fixed joint. The equations of motion are derived by Lagrange's Multiplier method and the resulting differential algebraic equations are solved in Gears method in ADAMS [9].



a) Stowed configuration

b) Deployed configuration

Figure-3: ADAMS model of Hold down mechanism

3.2 Modelling Latch-up

The latch-up modelling is essentially a transient dynamic analysis, begins after the completion of the deployment dynamics. The angular velocity just before latch-up obtained from the deployment dynamics is taken as the initial condition.

The linear velocity, v of the plate is normal to the plane of plate is given by

$$v = \omega x$$

where, ω is angular velocity just before latch up and x is the distance along the plate from the hinge.

The finite element model of the circular plate with latch simulated in MSC PATRAN is shown in Figure-4. The shell elements (QUAD4) are used. Revolute joint at the end of the plate is created through multi point constraints by releasing the rotational degree of freedom along the joint axis. The latch and the plate are connected through a high stiffness bush element. The model has 2378 QUAD elements.

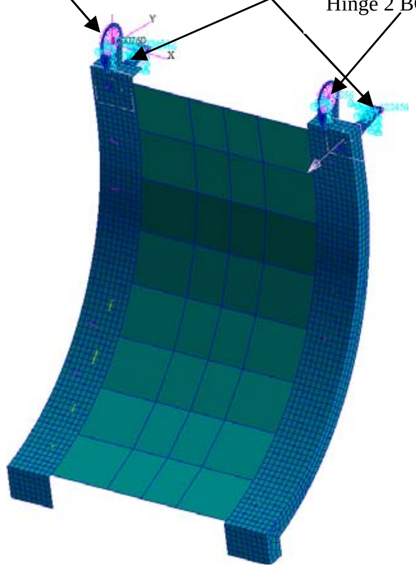


Figure-4 : FE model of Hold down plate

4 Results and Discussions

The physical parameters of the HDRM are presented in Table-1. The deployable circular plate will be latched once it is opened by 101 deg. The simulation is carried out by assuming the deployable plate to be rigid and flexible. Figure 3b presents the deployed configuration.

Table 1: Physical parameter of the hold down mechanism

S.No.	*Parameters*	*Value*
1	*Mass of each the Deployable Plate*	*0.621 Kg*
2	*Spring stiffness of each spring*	*124.9-Nmm/rad*
3	*Pre-rotation angle*	*3.141 rad*

The variation of angle of opening and angular velocity of the plate with time have been presented in Figue-5 and Figure-6 respectively. The plate will take 0.39 sec for rigid model and 0.38 sec for the flexible model to move from stowed configuration to deployed configuration. The angular velocity of plate just before latching for the rigid model and flexible models are 8.2 rad/s and 8.4 rad/s respectively. It can be observed from Figure 6 that the angular velocity plot shows oscillations due to the flexibility of the circular plate. The tip deflection of the circular plate during deployment is shown in Figure 7 and the magnitude is observed to be very low. The energy released by springs is 1.0 N.m, which is closely matching with the kinetic energy of the plate at latch-up.

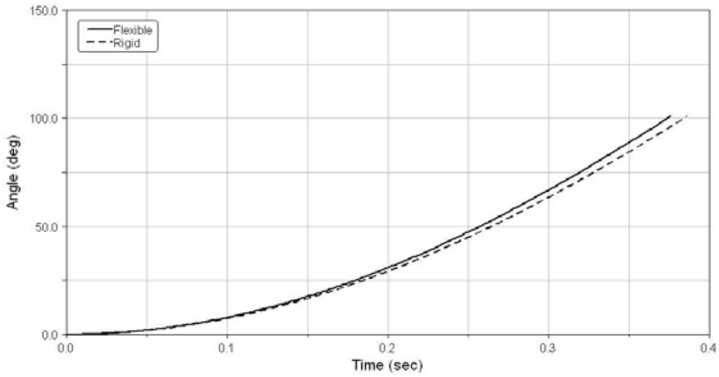


Figure-5: Variation of angle of opening with time

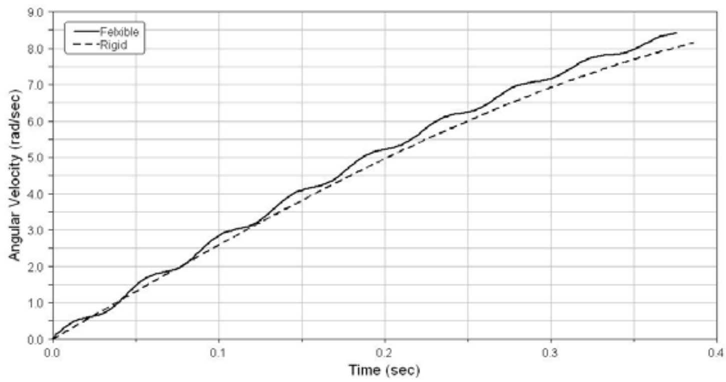


Figure-6: Variation of angular velocity with time

The tip displacement of the circular plate during deployment is presented in Figure-7. It can be observed that the tip displacement is very small and is 0.8 mm.

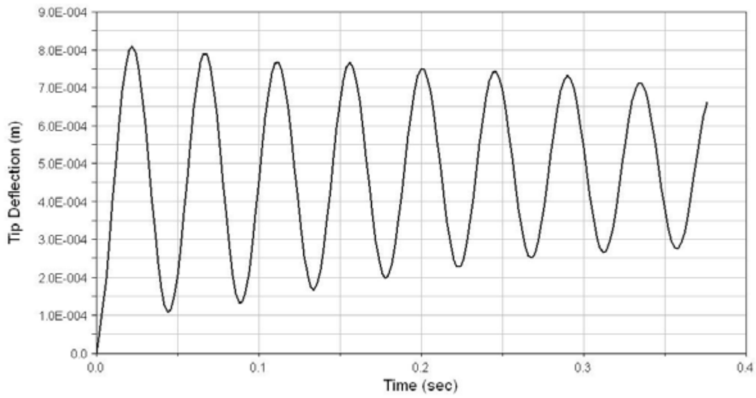


Figure-7 Tip displacement of the circular plate during deployment

The latching was modelled as a transient dynamic problem. The results are presented for both rigid and flexible model. As the time period of the first mode is 0.027 sec (37.66 Hz) , a step size for transient dynamics analysis should be lower than 0.0027 sec (one tenth of first fundamental time period.). To achieve the convergence on total energy, a finer step size of 0.00027 sec is chosen. The variation of force in the latch is presented in Figure-8.

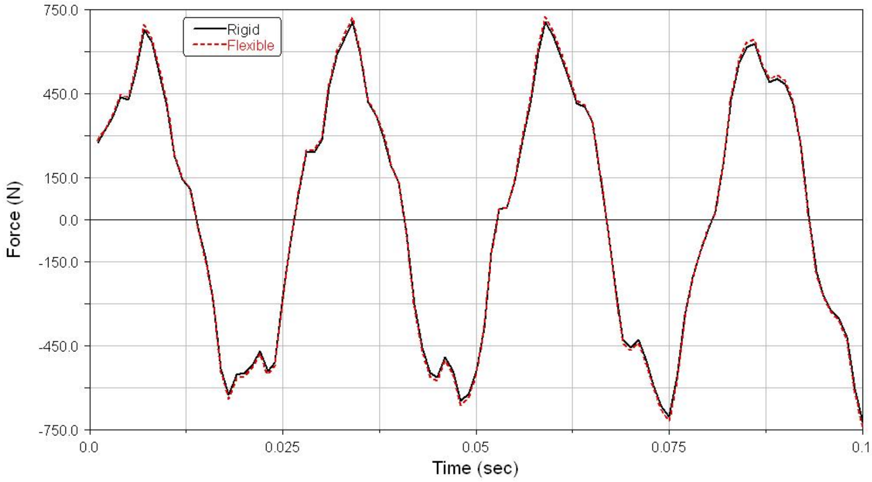


Figure-8: Variation of force in latch with time.

The peak force in the latch is found out to be 727 N for the rigid model and 738 N for the flexible model. It can be observed that the variation of latch force for the flexible and rigid model is not significant as the variation in latch up velocity for these models is very low. In order to study the reduction in latch-up force, a parametric study is carried out by reducing the spring stiffness to half. The results are reported in Table-2. It can be observed that the latch-up force reduces by 32.0%. The latch-up load forms the design input for latch and the circular plate brackets.

Table 2 Influence of variation of spring energy on latch-up force

Spring Stiffness (Nmm/rad)	*Deployment Time (sec)*	*Latch-up velocity(rad/sec)*	*Latch-up Force (N)*
124.9	*0.39*	*8.2*	*727*
62.45	*0.55*	*5.8*	*492*

5 Conclusions

The deployment dynamics and latching of HDRM used for the large aperture antenna is simulated. The deployment dynamics is carried out in ADAMS software by considering its flexibility. Transient dynamic analysis after latching is carried out in MSC PATRAN software. The latch-up load is evaluated. It was observed that the variation in latch up load and variation in latch up velocity is not very significant for the rigid and flexible model. The tip deflection indicated that the model is very stiff. The results of the analysis are validated by conservation of energy principle. The study provides design inputs for realising this mechanism.

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