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Supply Chain Management of Satellite Mechanisms- Product Development and Monitoring

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ABSTRACT
The project report primary deals with the Testing, Analysis, Modeling of the components of the Solar Array deployment Mechanism and a preliminary design. It also discusses the Monitoring of the supply chain management system for the procurement of the components from vendors. The deployment of solar array or any other appendage is a mission critical activity of any satellite. It is necessary to study about the deployment mechanism because once the array latches up, the satellite can have disturbance resulting in attitude change.
To begin, a detail study of the drawings of all the components, assemblies and sub-assemblies incorporated in the deployment mechanism was done. A literary review was carried out to investigate the research done previously and the research currently being done in the field of deployment mechanisms. This was followed by the designing of the components of SADM in Unigraphics. The components were assembled with their respective sub-assemblies. The next step was to perform the testing of components on various testing machines & thereafter analyzing the results. A conceptual design was prepared for the Solar Array Deployment Mechanism. A proper approach was used for the supply chain management of the procurement of raw materials.The torsion spring parameters were calculated, which importantly included the pre rotation angle, spring angular and the time required by the wings to deploy. The hinges were tested on the auto hinge characterization setup and the torque value required to deploy the wings was compared with the required value. The testing of micro switches was performed and the values of loads at actuation point, deactuation point, over travel and the gap between actuation and deactuation was compared with the actual values required. Torsion springs were tested and it was seen whether the stiffness values of the torsion springs are in limit to the defined value or not.Several components of Solar Array Deployment Mechanism were modeled in 3D. A simulating model of the preliminary design was made using Solid Works in which the deployment of the wings was shown by making use of the servo motor. The values of the torque required for hinges, loads at actuation point, deactuation point, over travel and the gap between actuation and deactuation and stiffness values of the springs were approximately accurate. Some errors had occurred due to the improper setup of the components on the fixtures.Unigraphics was used for the modeling of the components of Solar array Deployment Mechanism. The preliminary design was modeled and simulated in Solid Works.
Keywords – Satrellite, supply chain, unigraphics **.**

I. INTRODUCTION

Satellites orbiting the earth are destined to stay in space and continue orbiting for time immeasurable, and are expected to effectively send data to the Earth. These satellites need some source of power to function. No battery can provide power for such a long period of time. The obvious and most convenient source of power would be to harness the Sun’s solar energy. Thus, all the satellites have their own set of panels of solar cells that trap the Sun’s rays and produce solar energy. In satellites, solar panels are kept in the stowed condition while launching and are deployed after the satellite enters into its orbit. Deployment of these panels has considerable influence on dynamic and attitude control of satellite and may make disturbances. To prevent and minimize these disturbances in attitude control of a satellite, it is necessary to design a deployment mechanism for the solar panels which has appropriate performance and ability to control the disturbances. Solar Array used in satellites consists of a yoke and three to six panels are kept stowed during launch and deployment in orbit. The yoke and panels are interconnected by the hinges. The energy for the deployment is provided by the pre-loaded torsion springs mounted at each one of the hinges. The deployment is in a near accordion way to minimize the shock loads at the hinges. Close Control Loops (CCLS) are employed to achieve the accordion deployment. The satellite will have body rates due to separation disturbances at the time of injection into the orbit. The Solar Array Drive Assembly (SADA) is free to rotate at the time of deployment of solar array. During deployment of the array and because of body rates, the solar array is acted upon by an induced torque about the SADA axis which makes it to rotate. Because of this rotation, the solar array may hit any projection, which in turn affect the deployment and/or damage some sensitive devices In the early stages of space exploration when spacecrafts used to be small, mechanically simple and essentially devoid of flexibility, they were idealized as rigid bodies, essentially interconnected. However, for a modern space vehicle carrying deployable members, which are inherently flexible, this assumption is no longer true. These changes were due to following factors:

- In response to demanding mission requirements, satellite configurations have become more and more complex to maintain a delicate balance between diverse constraints of weight, space, performance control and their optimum realization.
- The ever increasing demand of power for operation of the on-board instrumentation, scientific experiments and communication systems has been reflected in the size of solar panels and antennas.
- Considering the power requirements, none of the batteries can run for a lifetime to support the satellites, which are destined to be in the orbit for time infinite and serve their purpose. Thus, the most beneficial power source would be to harness solar energy. Thus, all the satellites have their own set of panels of solar cells that trap the Sun's rays and produce solar energy.
- Complex operational satellites require large appendages (only in some missions) to detect low frequency signals.

To meet the mission requirements of weight reduction and efficient design of these systems, the designers must focus their attention on the interaction between structural vibrations, system dynamics and control. In order to keep up to these technology demands, one must understand the need of Solar Array Deployment Mechanism. The primary objective of the work is to study and understand the various assemblies incorporated in SADM. This is to be followed by the literary review & 3D modeling of different components and then assemble them with respect to their assemblies in Unigraphics. Analysis of different components and assemblies will be carried out using different testing mechanisms such as hinges and solar array drive assembly will make use of hinge characterization setup, spacers to be tested in friction test setup, torsion springs to be tested using Labview and torsion testing machine & micro switches using universal testing machine.The secondary objective is to provide a preliminary design and simulation for solar array deployment mechanism which will be less complicated and practically feasible. The design and simulation of the preliminary design will be carried out using Solid Works. The third objective, the monitoring of supply chain management of the components from several vendors acquired for SADM project will also be done. The models and assemblies can be assembled along with the satellite deck and a structural/flow analysis can be done using the ADAMS software. The preliminary design for solar array deployment will be a much less complicated design than the design being used currently for deployment.

II. II TESTING AND ANALYSIS

Automatic Hinge Characterization for different hinges and SADA

Hinge characterization testing system is specially designed and developed to test the angular deflection of the Hinge pairs. This System operates on servo motor with required speed and required angle. Servomotor is used for controlling the angular deflection of the clutches. High accuracy inbuilt encoder is used to monitor and control the angle. Reaction Torque sensor is used to measure Torque directly in terms of kgfcm. Different fixtures are provided to fix the hinge pairs. End limit proximity switches are provided to avoid the accidents to motor and safety of the fixtures. This torque is translated into electrical signal as change in resistance of strain gauges, the change in resistance indicates the degree of deformation which in turn directly proportional to

applied Torque. The Solar panels should deploy at a constant rate to avoid disturbances.[5]

3.2.2 Friction Testing Procedure for Spacers

The Purpose of this test is to ensure required minimum friction is generated in the fabricated aluminum inter panel spacers. It mainly consists of friction test setup, load cell and load setup. The test spacers and off-line test Delrin Spacers are mounted co-axially & loaded to the hold down load of W=X Kgf. Apply load laterally by rotating the gear box handle in the clockwise direction to move the rectangular block in the lateral position till the S type load cell DRO displays Y Kg. The spacer should not slide for the applied lateral load. In case there is no reduction in load on the display whilst increasing the load to Y kg the component will be acceptable or else the component will be rejected.

UTM testing of Micro Switches

The purpose of this machine is to find out force/displacement characteristics of limit switch.

Calibrate X &Y scale of graph plotter using a knowing/calibrated source of force/ deflection and record scale setting on the graph paper.Fix the limit switch on the holder. Torque the fixing screw to only X kgf-cm and not to a higher value. Position the plunger so as to load the lever at the specific distance from it fulcrum & apply the load gradually up to actuation. Apply load for Y mm more displacement (Over travel) beyond actuation and note down the load. The load Vs deflection graph (continuous graph) has to be plotted. Obtain actuation, de actuation and Y mm over-travel points from the graph. The acceptance criterion is based on the loads for actuation, deactuation, Y mm over travel and the gap between actuation and deactuation.Pawl Spring testing for finding the stiffness of the pawl springsThe purpose of the test is to find the stiffness of the pawl springs. Dismantle the 'L' Bracket of the fixture & Fix the Pawl Spring on the spacer provided on the shaft with one arm of the pawl spring below the 3 mm dia. pin provided on the pulley. Re fix the 'L' bracket with the other arm above the 3 mm dia. pin on the bracket. Now the system is ready for testing. Put equal weights on both sides of the pan to make the connecting rope slide properly on the pulley. Now rotate the wheel so that the 3mm dia. pin just touches the arm of the spring arm. Note the radial reading i.e. for load zero. Now load the pan with a wt. of 10 gm. on the spring compression side. Note the radial reading. Similarly perform it for every additional 10 gm. till a total of 40 gm. If the deflection is within limits the spring is acceptable or else it has to be rejected

Testing for Torsion Springs

Testing of the torsion springs is performed using Labview and Torsion testing machines. The main aim is to calculate the stiffness value of the torsion springs. Initially the value of the load as per the requirement is fixed and the RPM is set to a minimum value so as to avoid the occurring of the jerks. Spring is mounted on the mandrel such that it is in the ideal condition i.e. no external load is acting on it. Torque sensors are incorporated in the testing machine for the measurement of the torque. When the load value reaches to the specified load the load starts decreasing and thereafter the spring is unloaded. The lab view provides with the stiffness value, this value is used to calculate the pre rotation angle. Pre rotation angle is the angle which is initially given to the springs. This acts as a source of potential energy, which is used while for the deployment of the panels.After the completion of the testing and analysis of the components and assemblies a research on design considerations and material required for the production of components was carried out which was followed by the preliminary design of a deployment mechanism with the help of the Research department of Larsen and Toubro.

Material Selection

Mostly Aluminium 6061 alloy is being used for the manufacturing of all the components of SADM because of the following reasons:6061 is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties and exhibits good weldability. It is commonly available in pre-tempered grades such as 6061-O (annealed) and tempered gradessuch as 6061-T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged).The formula can be used for various strengths and modulus.

$$X(\text{Score}) = \frac{\text{Strength or Modulus (Property)}}{(\text{Cost} * \text{Density})}$$

Material	Tensile Strength (MPa)	Cost ($/kg)	Density (kg/m^3)	Score
Al Alloy 7075 T6	570	9.5	2.7	22.22
Al Alloy 6061 T6	300	5.5	2.7	20.20

Table 3.2: Metallic Tensile Strength [8,9]

The alloy composition of 6061 is:

- Silicon minimum 0.4%, maximum 0.8% by weight
- Iron no minimum, maximum 0.7%
- Copper minimum 0.15%, maximum 0.40%
- Manganese no minimum, maximum 0.15%
- Magnesium minimum 0.8%, maximum 1.2%
- Chromium minimum 0.04%, maximum 0.35%
- Zinc no minimum, maximum 0.25%
- Titanium no minimum, maximum 0.15%
- Other elements no more than 0.05% each, 0.15% total
- Remainder Aluminum (95.85%–98.56%)

The mechanical properties of 6061 depend greatly on the temper, or heat treatment, of the material. Young's Modulus is 10×10^6 psi (69 GPa) regardless of temper. It is a versatile heat treatable extruded alloy with medium to high strength capabilities. Melting Point: Approx. 580°C. The basic characteristics of 6061alloy are:

- Medium to high strength
- Good toughness
- Good surface finish
- Excellent corrosion resistance to atmospheric conditions
- Can be anodized
- Good workability

As per the research carried out on the material considerations 7075 Aluminium alloy can also be used for the manufacturing of the SADM components because the following characteristics such as Elastic modulus, bulk modulus, density, Fatigue Strength, Hardness, Strength to weight ratio, tensile strength and shear strength are more as compared to the 6061 Aluminium Alloy. 7075 aluminum alloy's composition roughly includes 5.6–6.1% zinc, 2.1–2.5% magnesium, 1.2–1.6% copper, and less than half a percent of silicon, iron, manganese, titanium, chromium, and other metals. But the cost factor comes into play, cost of 7075 alloy is almost double the cost of 6061 alloy. [10,11]

Preliminary Design

The present system involves a large amount of complexity due to the presence of hinges and springs. In the current system the springs will be stored with the certain amount of potential energy required to deploy the panels. When the potential energy will be released, deployment of panels will take place. The reliability of the deployment of the wings totally depends on these two. A proposal was made for making use of the rotors between the panels. As per the proposal a rotor will be mounted between the hinges of the panels which will help in the rotating of the solar panels. The design of the hinge was done with respect to the dimensions of the panels taken from [1]. The modeling of the Preliminary Design was carried out using Solid Works. The dimensions of the panels are as below:

Length of Panel (m)	1.40
Width of Panel (m)	1.80
Length of yoke (m)	1.70

III. RESULT ANALYSIS

This chapter will discuss the result analysis of the Automatic hinge characterization for different hinges & SADA, UTM testing for micro switches and torsion testing for springs. It will also discuss about values obtained for the spring parameters.

Auto Hinge Characterization

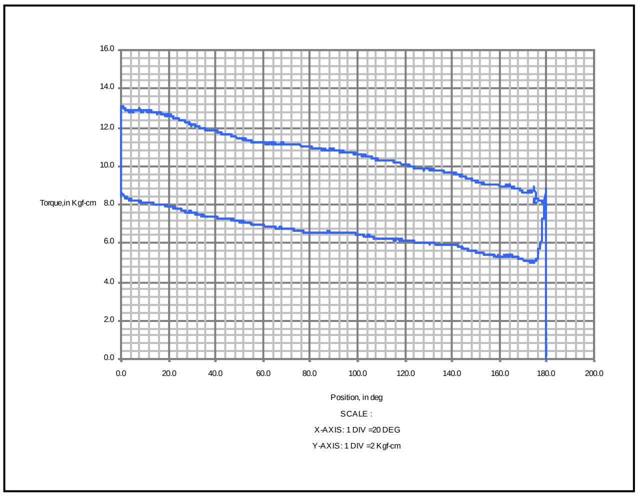

Figure 4.1: Hinge characterization graph

The graph that has been plotted with the help of the auto hinge characterization machine shows that whether the torque required for stowing and deploying the panels is within the limit or not. The panel goes from 180^o to 0^o. The lever is provided with a certain amount of torque which is acted onto the panels. As the torque exceeds the resistance provided by the panel, panel starts its angular displacement 180^o to 0^o. At 175^o the cycle is stopped for a second and the pawl is engaged. This leads to the increase in panel resistance therefore the torque required suddenly. increases. After the panel has moved from 180^o to 0^o, this implies it has reached the stowing condition. When the release of the panel starts taking place, resistance of the panel decreases and hence torque value decreases. This marks the beginning of the deployment cycle. The torque required keeps on decreasing with the angular displacement taking place. As the panel reaches 175^o pawl gets engaged into the cam profile therefore there is a sudden rise in the torque required to move the panel. When the panel reaches 180 degrees, load value decreases to zero.

Universal Testing Machine for testing of micro switches

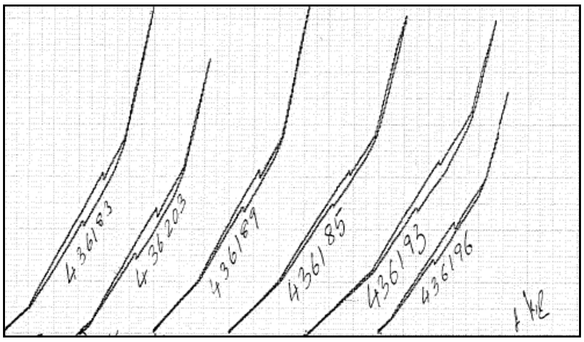

Figure 4.2: Graph of Micro switch Testing

The graph shows testing of six micro switches. Considering the micro number 436183. The Micro switch is loaded on the universal testing machine. The load keeps on increasing gradually till the actuation point. When the top lever of the micro switch touches the bottom lever, actuation takes place. Point A on the graphs shows the exact position where actuation is taking place. As the actuation takes place there is small sudden drop in the load. Micro switch is loaded till 1 mm after the actuation has taken place. The path it traces till the maximum load point is referred to as the Over travel. At the same rate of speed the load is decreased and the reverse. graph is plotted. The point where there is a sudden increase in the load value that point is referred as De actuation point. The acceptance criteria is based on the loads at actuation point deactuation point, Y mm over travel and the gap between actuation and deactuation. The values of the torque required for stowing/ deployment were found within the limit of the actual torque required. The stowing and deployment curves should be linear but because of some minor problems in the test setup the curve isn't linear. Loads at actuation point and the deactuation point were found to be within the limit. Ymm over travel and the gap between actuation and deactuation were also satisfying the required conditions for micro switches. The mounting of the spring on the mandrel should be done properly and it should be checked that initially the spring is in an ideal condition. The rpm of the rotor should be kept as minimum as possible, so as to avoid the occurrence of the jerks. The occurrence of the jerks will lead to a sudden rise/fall of the load values. The stiffness value of the springs matched the required values.Several spring parameters were obtained on the basis of assumptions.

IV. Conclusion and Future Scope of Work

The objectives of the project were to model the components of Solar Array deployment Mechanism in 3D, assemble them in their respective assemblies and coming up with the complete model. This was to be followed up by performing tests and analysis on several components on their respective testing setups. A conceptual design also had to be prepared and simulated in solid works. Simultaneously monitoring of the supply chain management of the components had to be performed.The Unigraphics software has been used for the modeling and assembling of the components of Solar Array deployment Mechanism, such as hinges, brackets, bolt terminals, spacers, springs, model of the satellite with the wings being in the stowed condition etc. Testing and analysis on various components and sub-assemblies was carried out on their respective testing setups. A preliminary design was provided for the deployment mechanism in which a proposal for making use of servo motors instead between the panels was made. Simulation of the preliminary design was performed on Solid works. Status of the components under manufacturing processes and secondary treatments was updated weekly on excel sheets and presented in a graphical format.

As per the idea of making use of the servo motors for deployment of the wings, the simulation of the initial design along with all the assemblies can be tested in ADAMS to study the structural analysis, and deployment dynamics of solar array with spacecraft body rates. The deployment dynamics study takes into account the measured hardware characteristics such as fiction torque characteristics. A comparative study between the use of the servo motors and mechanically actuated devices that is the current mechanism can be carried out. The results obtained can be analyzed for both of them.

The load on the satellite (communication or navigation) keeps on varying depending upon the mission requirements. The material used for the production of panels & the number of solar cells incorporated on the panels to supply the energy to the satellite to move in the orbits are also the factors. Keeping these factors in mind, a sufficient amount rotor power will be required for the deployment of the panels.7075 Aluminum alloy can also be used for the manufacturing of the SADM components because of the following characteristics such as Elastic modulus, bulk modulus, density, Fatigue Strength, Hardness, Strength to weight ratio, tensile strength and shear strength are more as compared to the 6061 Aluminum Alloy. Though there hasn't been any problem related to the use of 6061 Aluminum Alloy, but for more reliability 7075 aluminum alloy can be considered and used for the production of the components of SADM.

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