

Optimization of Ball Lock Separation System

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ABSTRACT

The Ball Lock Separation System is used in space vehicle to separate modules at different stages for jettisoning. The expended parts of space vehicle must be separated during flight at different stages to minimize the total load. The separation must occur at the correct time of flight and with minimum change in projectile velocity and rotational rate. During the separation stage, there must be minimal impact or detrimental shock load experienced by the structure for minimal change in trajectory. In this paper, mechanical design of the Ball Lock Separation System, which comprises of fore ring, retainer ring, aft ring, springs (Jettison System), balls has been designed and analysed. This study aims for optimizing the design using Design of Experiments method. Various types of springs viz., helical spring and disc spring have been experimented and optimized. Along with the optimization, system dynamics and performance reliability have been checked using multi body dynamics (MBD) and finite element analysis (FEA) tools. The results obtained from the software is compared with analytical solutions.

Keywords— Aerospace Mechanism, Design of Experiment, Finite Element analysis (FEA), Multibody dynamics, Optimization.

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I. INTRODUCTION

The Ball Lock Separation System is used in space vehicle to separate modules at different stages for jettisoning. The expended parts of space vehicle must be separated during flight at different stages to minimize the total load. The separation must occur at the correct time of flight and with minimum change in projectile velocity and rotational rate. During the separation stage, there must be minimal impact or detrimental shock load experienced by the structure for minimal change in trajectory. Based on the ball lock separation mechanism established for a micro satellite system by the Indian Space Research Organization (ISRO) for deploying microsatellite has been used in Polar Satellite Launch Vehicle (PSLV) successfully. The launch failures of PSLV-D2 on 20th September 1993, due to an unexpectedly large disturbance at second stage separation and partial failure of PSLV – C1 on 29 September 1997, due

improper placing of the satellite are some of the typical examples where the main cause of the problem is the faulty design of separation systems.

The ball lock system consists of these components a) fore end ring which is connected with satellite body, b) aft end ring connected with the parent body, c) retainer ring which is required to rotate by shearing the shear pin, it also carries out the function of retaining the balls interfacing between fore end ring and retainer ring during normal assembly, d) Pyro thruster assembly which is required to rotate the retainer ring through specific angle, e) balls holds the fore end ring and aft end ring together which are attached to re-entry payload module and carrier, f) spring assembly which provides the energy to accelerate the satellite body to the required velocity. The ball lock separation system work in these stages a) Pyro thruster gets activated by pulse b) Due to Pyro thruster action, rotation of the retainer ring takes place through specific angle and the pins get sheared, c)

Balls get some passage to move in retainer rings, d) Due to energy stored in the spring, spring will try to expand its limit state and this time balls enters into the retainer rings, e) The energy stored in the spring produce a displacement of the fore end ring.

D. Jeyakumar [1] this paper gives the information about the coordinate systems, its coordinate transformations and equations of motion used in the design and analysis using helical compression spring developed for satellite separation system. B. N. Rao [2] this paper shows a systematic formulation for the rigid body dynamic simulation, including the simulation of short period dynamics, inherent to jettisoning parts and stage separation of a satellite launcher. The problem is complex in nature; the procedure involves iterations at successive lower abstraction in separation system. The best choice of the author had used object oriented programming technique to tackle this kind of problem. The necessary classes have been divided to present different entities in the launch vehicle separation.

Design of Experiments (DOEs) refers to a planned, structured method, which is used to evaluate the relationship between various factors that affect a project and the various outcomes of a project. DOE can be used to reduce costs of design by reducing late engineering design changes, speeding up the design process, labour complexity and reducing product material. Design of Experiments are also powerful tools to achieve minimizing the manufacturing cost by reducing rework, scrap, minimizing process variation and the need for inspection. Multibody simulation is a used to conducting motion analysis. Multibody simulation (MBS) is a method of numerical or calculation simulation in which systems are composed of different elastic or rigid bodies. Connections between the bodies can be defined with force elements or kinematic constraints. Coulomb-friction and Unilateral constraints can also be used to generate frictional contacts between bodies. It is frequently used during product development to reveal the characteristics of performance, Comfort, and safety. In this paper, using Multibody simulation, design of experiment of different springs has been carried out.

II. SPRING DESIGN

Springs are mechanical devices which are used to damp or store energy or release energy if they are in pre-compressed state. The ball lock separation system is already optimized with the other parameters. There will be one chance to optimize the ball lock separation system to work on spring assembly design. For this paper work, take two different springs, a) helical compression spring b) Belleville spring or disc spring. The parameters which mainly affect the design of spring are a) preload in the spring b) distance travelled by spring effectively the stiffness of the spring. The spring is designed for velocity of 0.1 ± 0.01 m/s.

A. Helical compression spring

A helical compression spring, is a device, used to absorb shock, to maintain a force between contacting surfaces or to store energy and subsequently release it. They also offer resistance to axially applied compressive force. They are manufactured from an elastic material which formed into a helix shape which regains its natural or free length when unloaded. They are usually manufactured with a constant diameter, though they can be manufactured in other needed

forms such as convex (hourglass), concave (barrel), conical, or various combinations of these. Helical compression springs are widely used in: Valves, Actuators, Locomotives, Railroad, Agriculture, Elevator, Mining and Aggregate, Construction, Petrochemical, Pipe Hanger & Support, Playground, Industrial Equipment, Material Handling, Automotive, Power Generation, Transportation, Vibration Isolation, and Nuclear. The material used for helical spring is spring steel. It is used because it is easily available in the market and also it is chipped. It also resists corrosion. Its mechanical properties are young's modulus is 2.1×10^5 N/mm², Poisson's ratio is 0.3, density is 7.8×10^{-6} Kg/mm³.

The helical spring have different parameter for design: [3] D = 16 mm, d = 2 mm, no. of turns = 14, maximum δ = 32 mm,

G = 81370 N/mm² using this combination we get,

C = 8, $K_w = 1.184$, K = 2.838 N/mm, F = 90.8147 N,

Shear stress = 547.6267, Compressed length = 35.8

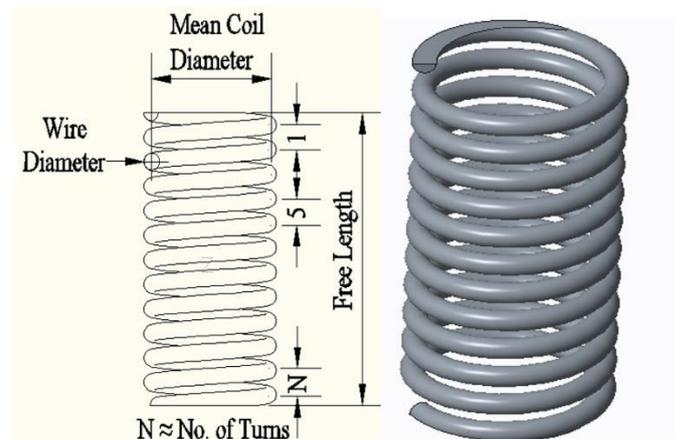


Fig.1 General Terms for helical compression spring and Its model using CAD software

Fig.1 shows that general term for helical compression spring and with that model developed using CAD software Pro-E wildfire 5.0. Fig.2 Shows spring assembly concept for required velocity and its Multibody dynamic simulation in MSC. Adams 2012. By using impulse force equation at a distance of 0.87mm from cylinder ground face in helical assembly, we can achieve velocity of 0.1 m/s in 0.0172 sec. As shown in Fig.3, it is shown that for a displacement 0.9347mm of helical spring with dimension parameters, velocity of 0.098 m/s achieved in 0.0173 sec. The weight of the total spring assembly is 0.0785 kg.

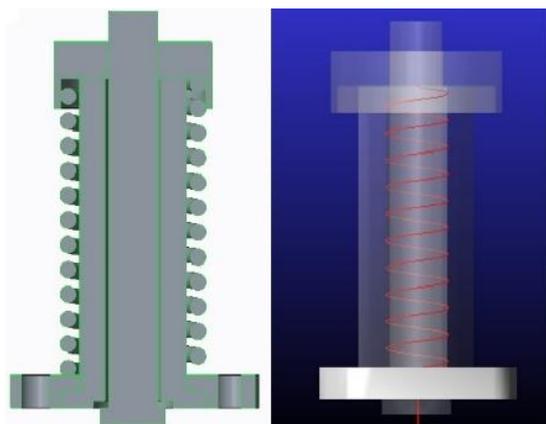


Fig.2 spring assembly concept using CAD software and its Multibody dynamic simulation using MSC. Adams

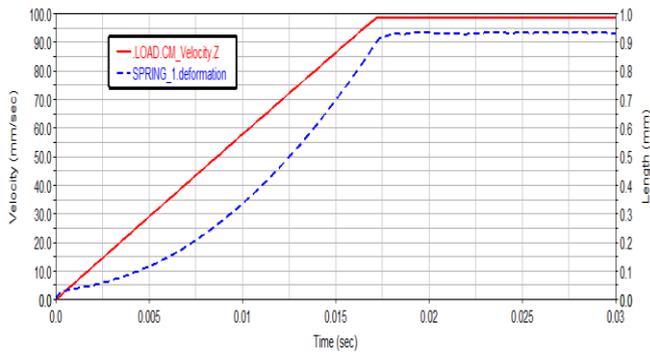


Fig. 3 MSC. Adams results for deformation of spring and velocity achieved by load after deformation of spring

B. Belleville spring or disc spring

A Belleville spring is a spring shaped like a washer. It has a conical (frusto) shape which gives a spring characteristic to the washer. Disc Springs are washer-type conically-shaped components designed for axially loaded. Disc Springs can be loaded dynamically subjected to continuous load cycling or statically either continuously or intermittently. They can be used as single spring or in multiples, or stacked series, in parallel or in a combination of both. There are a number of Applications of disc spring are: Heat Exchangers, Boilers, Furnaces & Ovens, Oil Industry, Petrochemical Industry, Food Processing Equipment, and Chemical Processing. The Belleville spring requires a very high compressive load to deflect spring in macros. They can be used in utilities where a standard helical spring would be largely unsuitable. They have more capabilities, including a low tendency to creep and a high tolerance to fatigue, disc springs have seen use in locking devices artillery pieces, Formula One Cars and firearms. The material used for disc spring is spring steel. It is used because it is easily available in the market and also it is chipped. It also resists corrosion. Its mechanical properties are young's modulus is 2.1×10^5 N/mm², Poisson's ratio is 0.3, density is 7.8×10^{-6} Kg/mm³.

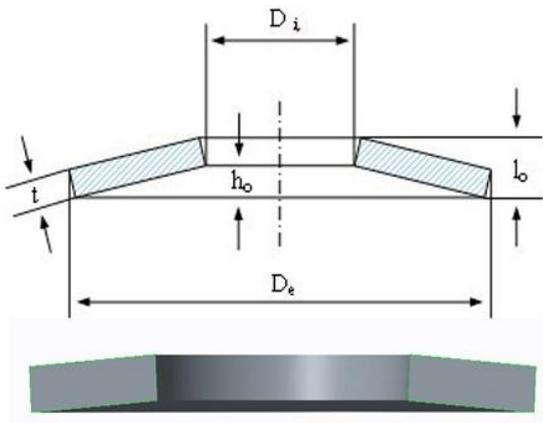


Fig.4 General Terms for disc spring and its model using CAD software

Disc spring is modelled using parameters as given: [4]
 $D_o = 13.5$ mm, $D_i = 6.7$ mm, $t = 0.8$ mm, $h_o = 0.4$ mm
 $l_o = 0.8 + 0.4 = 1.2$ mm, $E = 206000$ N/mm², $\mu = 0.3$,
 Using this combination we get,

Preload force = 557.6615 N, $s = 0.14$ mm, spring rate = 3983.2968 N/mm.

Fig.4 shows that general term for helical compression spring and with that model developed using CAD software Pro-E wildfire 5.0. Fig.5 Shows spring assembly concept for required velocity and its Multibody dynamic simulation in MSC. Adams 2012. By using impulse force equation at a deflection of 0.14mm disc spring. We can achieve velocity of 0.1 m/s in 0.0028 sec. As shown in Fig.6, it is shown that for a displacement 0.14 mm of disc spring with dimension parameters, velocity of 0.097 m/s achieved in 0.003 sec. The weight of the total spring assembly is 0.06075 kg

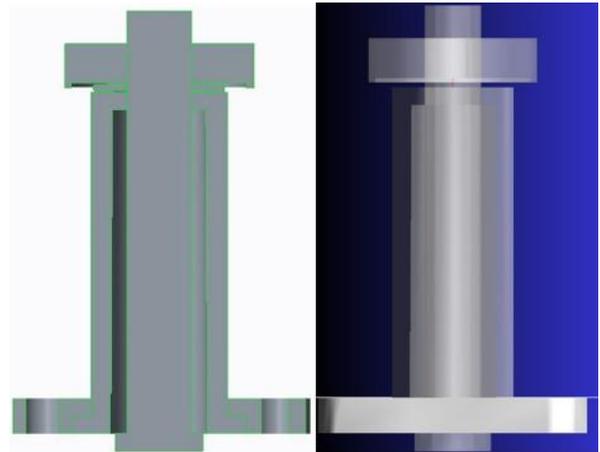


Fig.5 spring assembly concept using CAD software and its Multibody dynamic simulation using MSC. Adams

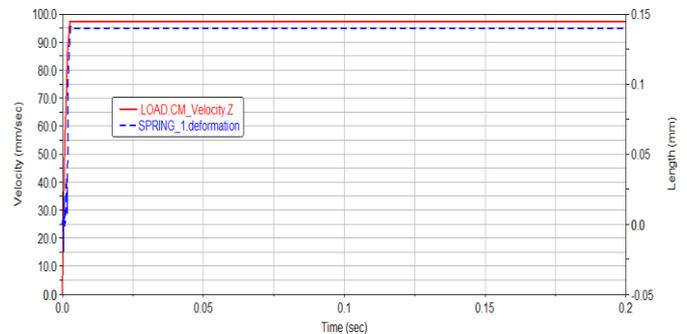


Fig. 6 MSC. Adams results for deformation of spring and velocity achieved by load after deformation of spring

III.CONCLUSION

1. It reveals that a maximum of 7% of error found in results and weight reduction in disc spring is 0.01775 kg.
2. The ball lock separation system consist of 32 spring assembly. The stopper is eliminated from disc spring, which is not required to stop deflection of the spring. Due to this total weight of 0.568 kg is reduced.
3. The distance travelled by disc spring is reduced by 0.73 mm.

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