Separation Connector

By
Koll Christianson, Luis Herrera,
and Zheng Lian
Team 19

Prototyping Progress Update

March 1, 2013

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design – Fall 2012

Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

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1. Introduction

Orbital Sciences Corporation is an engineering design company that contracts in space vehicles and missile defense systems. Our sponsor, Mary Rogers, is their current electronics packaging and actuator manager. She has requested, on behalf of Orbital Sciences Corporation, that our capstone group aid in redesigning the separation connector that is currently in use (See Figure 1 below). The separation connector is a mechanical device that allows the communication wires between the stages of a launched space vehicle or missile to be safely disconnected. The current separation connector being utilized by Orbital Sciences Corporation is difficult to de-mate and manufacture. Our team has designed the "Ball Bearing Detent" design to solve these problems. The Ball Bearing Detent design requires far less force to achieve de-mate, is easy to manufacture, and is as reliable as its predecessor.

Figure 1: Current separation connector

1.1 Problem Statement

The goal of this project is to design and prototype a relatively easy to manufacture, inexpensive, and perfectly reliable separation connector.

1.2 Project Goal

It is essential that the new separation connector mates and de-mates at least 50 times with no signs of damage or failure. Thus, the goal of the project is to design an improved separation connector that will separate cleanly 100% of the time. Static de-mate, for this new separation connector, will be achieved when a force of 10-30 lbf is applied to it and it will be able to withstand a force of 200lbf during dynamic de-mate. Lastly, the entire design will be easy to manufacture so that it can be machined in-house by Orbital Sciences Corporation's machine shop.

2. Preliminary Design

The "Ball Bearing Detent" design is the most recent design that was prototyped. This design has undergone extensive modifications in order to meet the requirements and constraints given. The design consisted of six part major pieces: a male end, a female end, a coupling connector, a pressure plate, the ball bearing retention ring, and the leash ring. The minor pieces included: a wide spring for the pressure plate, six ball bearings, six smaller springs that rest behind the ball bearings, and a leash cord.

This design was projected to statically de-mate when a force of approximately 30lbf is applied to both ends in opposite directions. This condition is also true for dynamic de-mating as the separation connector will be located inside of a rocket and will not experience too many external forces. However, the device has potential to experience higher pull forces during flight as opposed to being on the ground. These higher forces are the forces experienced when, for example, a rocket has separating stages. When the stages separate, one end will continue its flight causing a high pull force on all of the internal components. To account for these high pull forces, we have designed our separation connector to be able to withstand forces of up to 200 lbf. This ensures the parts used in separation connector will not shear or catastrophically fail due to instant "shock" forces that may happen during flight.

2.1 Final Design Description

This design, shown in figure2 below, utilizes the original male end and a modified female end. Both ends connect to each other by being inserted into a third piece, the coupling. There are two ways to insert the two ends of the separation connector. The first style is called a "twist-pull" style. The male end inserts into the coupling by twisting it clockwise one-third of a turn, which allows the bayonet pins to follow a track on the inside of the coupling. When it reaches the end of the track, the pressure plate inside of the coupling applies an opposing force that forces the bayonet pins into a groove and mates the male end to the coupling which will achieve a mate. The second style of mate is called a "push-pull" style mate. In this type of mating, the female end is forced into the back of the coupling. When the female end is pushed into the coupling, the ball bearings will retract allowing it to enter the coupling. When the ball bearings reach the inner groove cut into the coupling, the ball bearings will expand and mate the female end to the coupling.

In order to de-mate the device there must be a pulling force on both ends of the connecter. The ball bearings on the female end will retract when approximately 30lbf of force is applied to them. This allows the female end to detach both statically and dynamically. For static de-mate of the male end, the male end must be pushed down and twisted counter-clockwise one-third of a turn simultaneously. The male end will not de-mate during dynamic conditions. Instead, the female end will be removed and the coupling will stay with the male end.

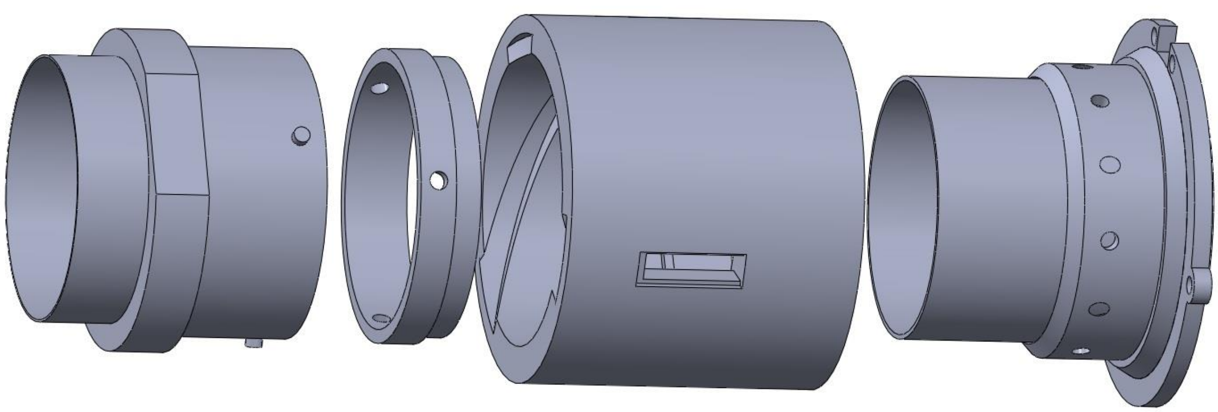

Figure 2: Exploded view of the preliminary design

2.2 Major Pieces

- Male end
  - Due to the customer's constraint, we were unable to change this part. Therefore, this part remained the same as the original design.
- Female End
  - This piece is a simplistic shell that holds all of the communication wires. It has an extrusion on the bottom half with holes tapped in it to hold the springs that apply force to the ball bearings. It will contain the springs and ball bearings when the ball bearing retention ring is put on.
- Coupling
  - This piece is a coupling that has grooves cut into both ends to accept both the male and the female ends. The end that accepts the male end has a helical groove that allows the male end to rotate one-third of a turn (as per military specifications). The end that accepts the female end has a circular (180°) groove cut into it to accept the ball bearings. When the ball bearings are pushed into the coupling, they compress. The ball bearings will expand when they hit this groove causing it to mate with the coupling.
- Pressure Plate
  - This piece in its simplest form is a ring. The ring is has three holes in it that will be threaded to hold 1/10" screws. The ring is placed on top of the wide spring and both are placed inside the male side of the coupling. The screws act as pins and travel along a slit cut into the coupling to keep the plate from rotating. The main purpose of this piece is to compress when the male end is inserted and expand when the male end reaches the end of the track; thus, holding the male end in place.
- Ball Bearing Retention Ring
  - This piece is the outer ring that holds the ball bearings in place on the female end. It has six chamfered holes that allow the ball bearings to extrude out from the surface. The smaller holes are for setscrews. The setscrews will secure the ring onto the female end and ensure that the ball bearings do not fall out.

- Leash Ring
    - The leash ring is a constraint requirement. Its function is to allow the attachment of a leash to our separation connector. This ring is attached to the female end of the separation connector in this design as seen in figure 1. Its primary use is to avoid separation by pulling on the cables.

2.3 Minor Pieces

- Wide Spring
    - This spring is for the pressure plate. It has a wide inner diameter that will fit inside of the coupling on the male end. The spring will contract when the plate applies pressure to it and expand when the male end reaches the end of its track; thus, holding the male en in place. This piece will be purchased from a catalog
- Ball Bearings
    - There are six steel ball bearings. Each ball bearing has a diameter of .1”. They will be purchased from a catalog. The ball bearing will be held to the female end with help from the ball bearing retention ring. Behind each ball bearing, there will be a small spring to allow the ball bearing to retract into the female end when a force is applied to it. The ball bearings expand when the force is no longer being applied. For example, in our design the ball bearing retracts when the female end is forced into the coupling and expands when it reaches the inner groove of the coupling; causing them to be mate.
- Ball Bearing Springs
    - There are six small springs. These springs sit behind the ball bearings on the female end. They allow the ball bearings to expand and contract when forces are applied and removed from them.

- Leash
    - The leash is a simple wire cord that is attached to the leash ring on the separation connector. It is used in union with a lanyard which is attached to a launch pad or the side of a stage (of a rocket) that is going to be separating. As a stage separates, it generates the pull force required to separate the two ends of the separation connector. This pull force is applied to the leash, allowing the female end to be pulled away from the male end of the separation connector.

3. First Prototype

The first prototype (figures 3 and 4 below) was created using fused deposition modeling (FDM). Creating the first prototype was very useful for the team in understanding how our design functioned. However, there were several design flaws that were not visible in the solid works models. When assembling the prototype, it became apparent that the key on the female end was missing. The key allows the wires on the female end to be connected correctly the wires on the male end. By adding the key to the female end, it created another problem. Our original design did not account for the key so adding it would not allow the ball bearing retention ring to slide on without the proper key slots. This brought up another concern regarding the ball bearing retention ring. Because of the precise and small dimensions of the separation connector we found that it would be difficult to assemble the ball bearings and springs behind the retention ring. Taking these design flaws into account, we began to redesign our separation connector to create a more effective design.

Figure 3: Exploded view of first FDM prototype

Figure 4: First FDM prototype fully assembled

4. Design Modifications

To account for the problems mentioned in section 3 above, several pieces of our design had to be changed. Each adjustment is listed below under the piece that it is modifying:

1. Coupling
   - Fixed measurements of helical grooves to match the military specifications
   - Added easy cut slots at the end of each groove. The slots are where the bayonet pins rest while mated
2. Female end
   - Added key extrusions to match the male end
   - Combined it with the ball bearing retention ring to make one solid piece
   - Cut holes with chamfered ends to fit the ball bearings and small springs
   - Made space for the spring retention ring
3. Ball Bearing Retention ring
   - Was combined with the female end to simplify the design and reduce the number of pieces in the design
4. Spring Retention ring
   - Was added to simplify how the design is assembled
   - This piece is inserted inside the back of the female end after the ball bearings and springs are placed

5. **Modified Final Design**

The modified design will work the same as the previous model. The biggest change is that the new design will be easier to assemble and will connect correctly with the male end 100% of the time. See below for the 3D SolidWorks models of the new design.

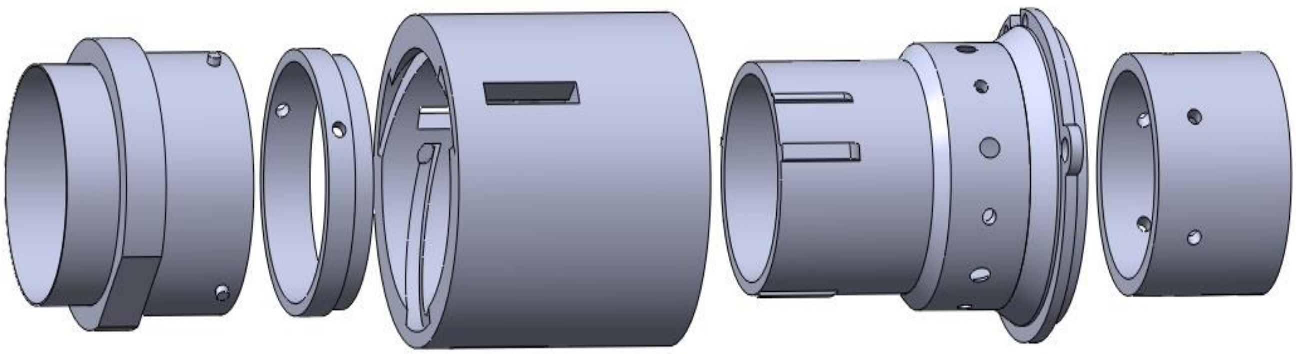

Figure 5: Exploded view of new design

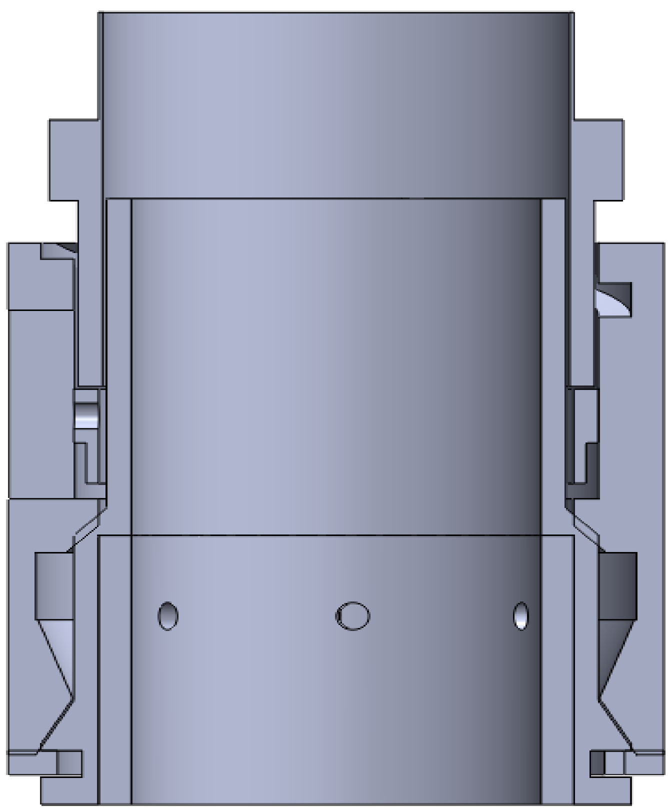

Figure 6: Fully assembled cross-sectional view of new design

6. Second Prototype

The next step is to produce a second FDM prototype. The second prototype will ensure that there are no further defects with our current design. If there are no further defects we will proceed to make a working metal prototype.

6.1 Materials

The second prototype will be made out of ABS plastic. It is a cheap alternative to making a metal prototype and will allow us to find if any problems remain in our design. After we finalize the dimensions and make improvements, we will produce a working metal prototype using Aluminum alloy 6061 – T6. As with the previous design, this design will utilize stainless steel ball bearings and springs. Stainless steel was chosen because of its low cost and corrosion resistance.

6.2 Component Manufacturing

This section will describe how we intend to produce our final metal prototype. Each piece of the design has its own complications and will be produced using different methods as described below.

- Female end

  The female end will initially be placed into a CNC mill to create the keys on the upper section of the part. Then the rest of the part will be made using a lathe. Another option we have is to use a CNC mill to create the whole part. The countersinks on the lower ring will be created using the same tool that bearing races are fabricated with.

- Coupling

  A machine shop off campus that has a helical gear cutter will be outsourced to manufacture the coupling. The helical gear cutter will be used to simplify the fabrication of the helical bayonet pin paths required for this part. The rest of this piece will be manufactured by a CNC lathe.

- Pressure plate and spring retention ring

  These parts will be created on a lathe in the NAU machine shop and then placed into a mill to create the holes required. Then each piece will be hand threaded using a tap after the holes are drilled out from the mill.

- Leash ring

  This part will be cut out of a piece of sheet stainless steel using a CNC mill.

7. Future Analysis

Currently, the analysis of our design is limited because there are many flaws with the FDM prototyping process that did not allow us to fully assemble our prototype. In addition, design modifications have been made to the prototype, so testing now would not accurately reflect the stresses on our current design. The completion of the second FDM prototype will ensure that all of the pieces of the design will have the correct fit and function. Once fit and function is achieved, a third prototype will be manufactured out of aluminum 6061-T6 and stainless steel. Lab testing will begin with the creation of the third metal prototype. The tests to be performed include: vibration, tension, torsion, and drop tests.

8. Project Plan

This section contains our updated Gantt chart. The Gantt chart shows the deadlines we need to meet to complete this project on time. This schedule is tentative and is subject to change. See figure 7 below for updated Gantt chart. (Updated 03/01/2012)

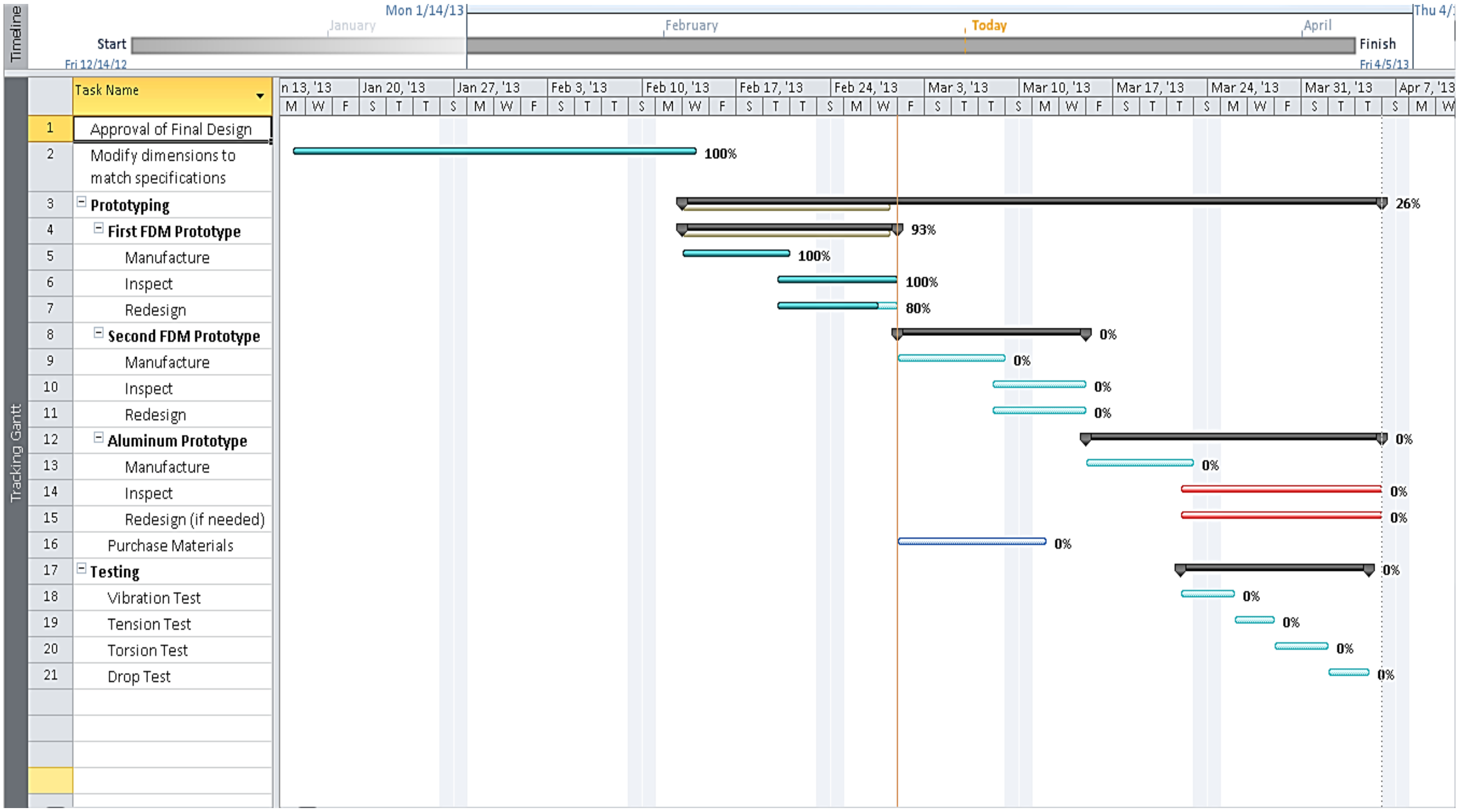

Figure 7: Updated Gantt chart

9. Conclusion

Our second prototype is scheduled to be printed before March 15, 2013. The feasibility of final prototype being successful depends on how well we manufacture, modify, and test our second plastic prototype. After our secondary prototype is made, we will modify our design as needed until the design is ready to make a working, metal prototype. We project that our first metal prototype will be ready before March 31, 2013.