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Design and Manufacturing of Mechanical Separation System

Nureddin Omar Fhailboom
University of Zawia
n.fahelalboum@zu.edu.ly

Abdulkarim Ramadan Alzahougi
High institute of science and technology- Zawia
aalzahougi@yahoo.com

Abstract

Rocket Stage Separation System Mechanism is very critical and an important operation during its journey. The Separation System is used to ensure safe and reliable separation of two rocket stages after termination of the thrust of the lower stage. The prepared separation system which is explosive bolts and manacle rings with the serving of spring thrusters for lateral displacement during the operation of separation has been used and experimented successfully. This study is used to present a whole and detailed review of designing of a complete separation system. All separation system components have been designed carefully and manufactured by CNC machines also simulated by Ansys software.

Key words: separation – explosive bolt – manacle ring – manufacturing.

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تصميم وتصنيع منظومة فصل ميكانيكية

نورالدين عمر حسين فحيل البوم
كلية الهندسة
جامعة الزاوية
n.fahelalboum@zu.edu.ly

عبد الكريم رمضان عمر الزهوقي
المعهد العالي للعلوم والتقنية
الزاوية
aalzahougi@yahoo.com

الملخص

تعتبر آلية نظام الفصل المستخدمة في مراحل الصاروخ عملية بالغة الأهمية أثناء رحلته. خلال هذا البحث تم إعداد وتصنيع منظومة فصل كاملة. هذه المنظومة عبارة عن مسامير متفجرة وحلقات ربط بمساعدة دافعات زنبركية للإزاحة الجانبية. وتم اجراء التجارب الأرضية لهذه المنظومة بنجاح. وقد تم تصميم جميع مكوناتها بعناية وتصنيعها ومحاكاتها بواسطة برنامج ANSYS. تستخدم هذه الدراسة لتقديم مراجعة كاملة ومفصلة لتصميم نظام فصل كامل.

الكلمات المفتاحية: الفصل – المسامير المتفجرة – الحلقة – التصنيع.

1.0 Introduction

Some parts of a rocket must be separated during flight to jettison stages and components that are no longer needed. For a mission to be successful, the separation must occur at the correct times of flight and with minimum changes in the attitude and rotational rates of the continuing body. There must be no re-contact between the separating bodies, no detrimental shock loads induced in the structure, and no excessive or harmful debris. A separation mechanism that does not meet these requirements can produce attitude errors and tumble rates of the continuing body that are too large for its attitude-control system to accommodate, can damage its structure and critical equipment, and can cause failure or degradation of the mission. The stage separation event of the launch

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vehicle occurs during a very short time and is related with many dynamic parameters [1].

2.0 Review of Literature

Separation systems are especially used for multistage rockets. This mission is accomplished by dropping mass throughout the burn so the next stage can be unweighted and coast for a long journey. Over time this technique inspired companies and researchers to immerse and deep-thinking throughout. Kinds of literature from scientific journals within the area of separation systems have been conducted and studied using electronic journal databases such as Scopus, Science Direct, and Emerald that publish. The concerned separation system is using a mechanism of explosive bolts and manacle rings technique has been studied and manufactured. The separation system is active and passive parts of a rocket [2].In sounding rockets the most important task of the separation system is separation of payload from motor [3].Design and simulation of separation of two bodies is a task of high complexity [4]. High-explosive separators used to separate structures in space systems and launch vehicles have many advantages, including low cost, high reliability, and high operating energy [5]. The explosive bolts are a type of pyrotechnic release devices in which two connected structures are separated by explosives [6]. When the separation signal is received, the separation nut begins to unlock and the spacecraft is released [7].Another type of separation system uses the mechanism of black powder ejection charge[8].

3.0 Objective

The main objective of this scientific research work is to conduct a comprehensive study of the separation systems by using the mechanism of explosive bolts and manacle rings technique, leading to publishing a document that contains restricted and unpublished materials in the field of flight technology, especially at separation systems. Generally, the design and manufacturing technology of the separation system is considered a very advanced technique due to

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its complicated components which requires a very highly advanced technical process during the manufacturing of all components, at the same time this technology requires special equipment and material with special specification to withstand the hard operating and testing conditions.

4.0 Methodology and Used Databases

Due to the scarcity of databases in the field of rocket separation systems, the researcher was encouraged to carry out this research according to the available capabilities. The total separation system has been designed by means of advanced computer programs and manufactured totally, at the Technical Research Centre (TRC). Many complicated manufacturing operations have been conducted such as advanced milling operations by specialized CNC machines to produce the complicated parts, as well as some Turning operations also by CNC machines have been achieved, also, extra manufacturing processes are needed to manufacture other parts. The results showed that the manufactured parts were compared to the computer drawings, which are very similar and closer to reality, the reason for that refers to the accuracy of the machines used in manufacturing.

4.1 Rocket Separation System

Multistage rocket generally termed as step rocket is a vehicle that uses two or more stages having its own engine and respective propellants [9]. The staging is a critical operation during the flight of the rocket. It allows to increase the performance of the rocket by increasing the rocket's total impulse and decreasing the rocket's final weight. A staged rocket has two or more motors that burn one after the other while dropping off the used stage or the used booster(s). The advantage of staging is that launch vehicle configuration can be optimized for the requirements of a particular mission by adjusting the amount of propellant and engine thrust and using different types of engines, propellants, and structural materials for various stages [10].

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4.2 Types of Rocket Separation System

The (R.S.S) or Multistage vehicles, the staging can be classified into main two types, they are:

A. Tandem or serial staging. **B-** Parallel Staging

A- Tandem or serial staging.

Tandem staging sometimes referred to as vertical staging, in which the first stage is ignited at launch and burns through the powered ascent until its propellants are exhausted, as shown in figure (1). The second stage separates from the first stage, and the second stage engine is ignited.

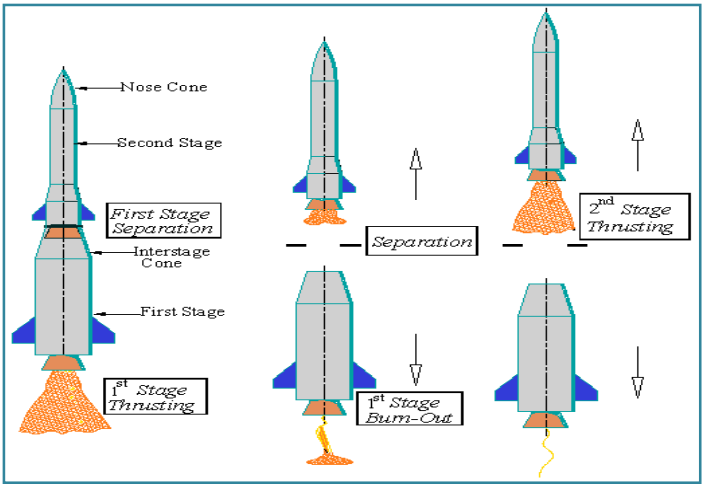

Figure (1): Separation Concept at Tandem staging

B- Parallel staging.

In parallel staging, two or several small rockets are strapped onto a central sustainer as shown in figure (2). The number of boosters is chosen according to the designing of the vehicle and according to the required thrust force. The use of solid rocket boosters to launch UAVs has the following advantages: less space required; no obvious constraints for environmental conditions; lower initial investment;

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no pressurization time required; after the launcher is installed, the UAV can still store for a long time [11].

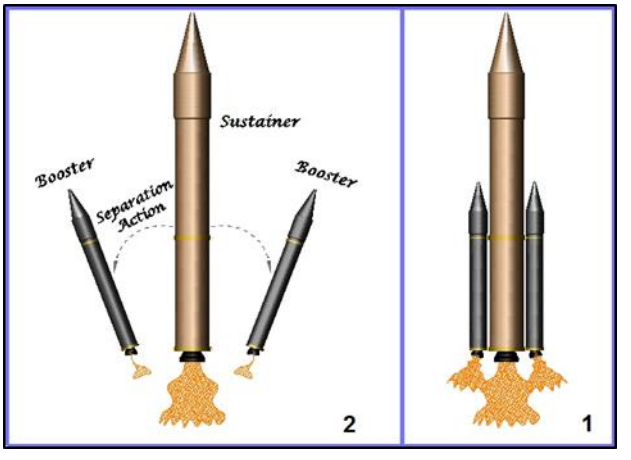

Figure (2): 3D Modeling for Parallel Staging

5.0 Separation System Specification / Requirements

The total manufactured components of the separation system composed of the main following parts (Manacle Rings – Explosive Bolts – Upper and Lower Shell – Coupling Rings – Thrusting System).

5.1 Manacle Rings.

The manacle ring is the mechanical connection between the forward and the aft ogive that is released by the manacle ring opener [12].The manacle rings are usually designed in two or more segments attached to each other by using explosive bolts. Figure (3) presents the manufactured manacle rings used on the separation system, meanwhile Table (1) contains the engineering specifications details of these rings.

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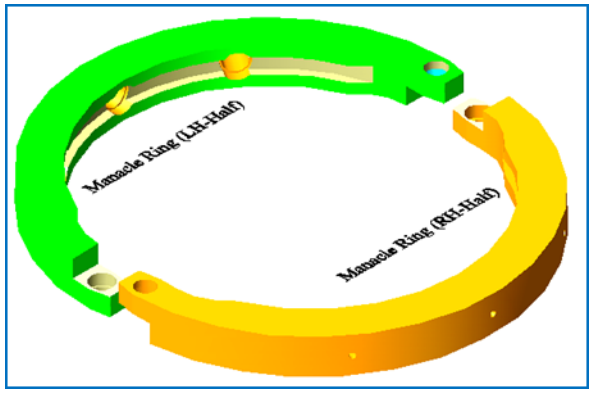

Figure (3): The manufactured Manacle Rings used in Separation System

Table (1) Specification of Used Manacle Ring

Portion	Description
1. Outside diameter	= Ø 418mm
2. Internal groove diameter	= Ø 355mm
3. Inside diameter	= Ø 338mm
4. Height	= 40mm
5. Explosive bolt hole diameters	= (Ø25×Ø21×Ø17) mm
6. Material	= (AA 2014T651/T652)
7. Estimated Mass for two rings	≈ 4.206 Kg

The steps of manufactured possess of Manacle Ring is illustrated in figure (4).

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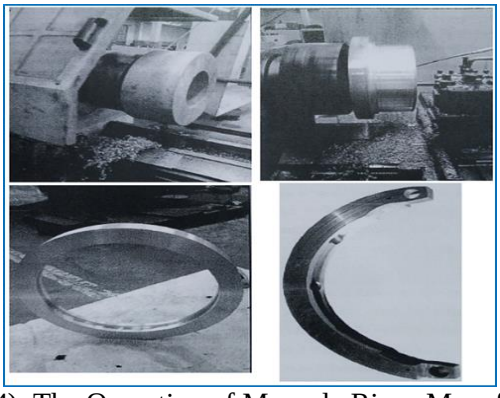

Figure (4): The Operation of Manacle Rings Manufacturing

5.2 Explosive Bolts

Explosive bolts are one type of reliable and efficient pyrotechnic release devices used for many applications [13].

The explosive bolts are a reliable fastening-release device which is attached temporarily with members or structures. Explosive bolt being used consists of a cavity in a tube filled with explosives which is assembled, and a nichrome wire (initiator) comes out of the tube from initiating secondary explosives [14].

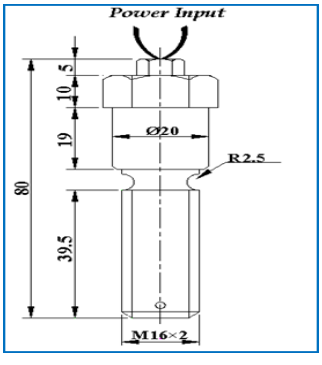

Figure (5): Manufactured explosive bolts used on the separation system

The explosive bolts are designed and manufactured for use in launch vehicles, missiles, aircraft, and other applications where

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rapid structure separation is demanded. Figure (5) shows the manufactured and tested explosive bolts used on the separation system, while Table (2) presents technical parameters of the bolts

Table (2) Technical Parameters Required for Explosive Bolt

Description	Details
1. Time for activation to destruction	= 0.002 Sec
2. Self-destruction temperature	= 120 ^{0}C
3. Electrical resistance of igniter bridge	= 1.8 - 4.5 Ohm
4. Minimum value of direct electrical current	= 0.18Amp
5. Recommended current	= 0.32Amp
6. Mechanical strength (For static loading)	= 52700 N
7. Free volume around destruction zone	= 6000 mm^3
8. Self-life time	= 2 years.
9. Bolt material	= Steel C 4570

5.3 Upper and Lower Coupling Rings

The Coupling Rings or connecting rings are mechanical connections between the stages as shown in figure (6), they are used to connect between the rocket stages or any other desired objects to be attached such as pipes, or oil pipes. These two coupling rings will be connected to each other by using the manacle rings. The specification of both used Coupling Ring are presented in table (3).

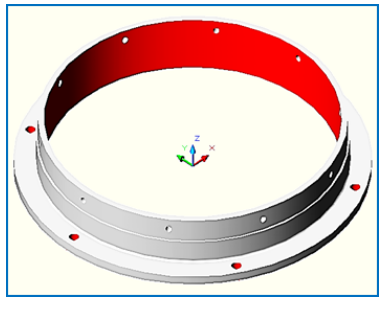

Figure (6): Manufactured Coupling Ring used on the separation system.

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Table (3) presents general details of the coupling rings.

Portion		Description
1.	Lower outside diameter	= Ø 355mm
2.	Upper outside diameter	= Ø 307mm
3.	Outside diameter	= Ø 311mm
4.	Internal diameter	= Ø 295mm
5.	Height	= 50mm
6.	Material	= (AA 2014T651/T652)
7.	Estimated Mass for one ring	≈ 1.50 Kg

6.0 Separation System Ground Testing

There were three types of ground tests have been achieved on the separation system to ensure all components are designed properly. Testing of explosive bolt individually (two tests) have been achieved successfully, also testing of two explosive bolts connected together with one circuit as shown in figure (7).

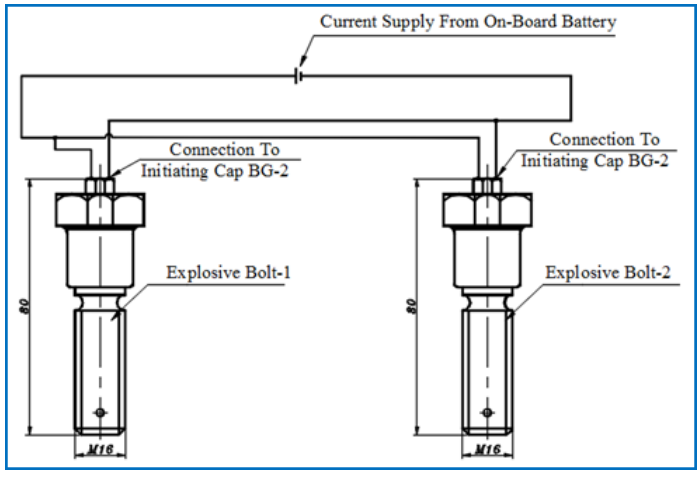

Figure (:7) Schematic Pyro-Circuit for Two Explosive Bolts

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6.1 Testing Method

The separation system testing method as shown in Figure (8) has been assembled as tested. As the separation command has been given, explosive bolts have been functioned and both halves of the manacle rings have come out from the separation joint, At the same time the interface ring has been separated from the interface coupling ring, and a cleared separation has occurred successfully.

Figure (8): Total System Prepared for Ground Testing

7.0 FEA Static Structural

From the obtained analysis by FEA, as shown in figure (9)(10) it is observed that with the application of all loads, the manacle ring may subjected to maximum stress of 41.325N/mm^2 however, these stresses are less compared to the yield strength of manacle ring material (AA 2014T561/T652) which is 390N/mm^2, while the maximum stress is 24.63N/mm2 occurs at explosive bolt region and the maximum axial force 31.124 N/mm2 at the periphery of explosive bolt hole due to stress concentration.

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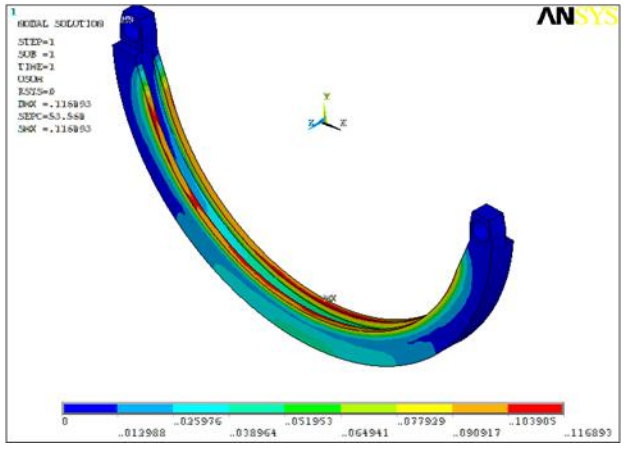

Figure (9): Displacement Values Obtained by ANSYS

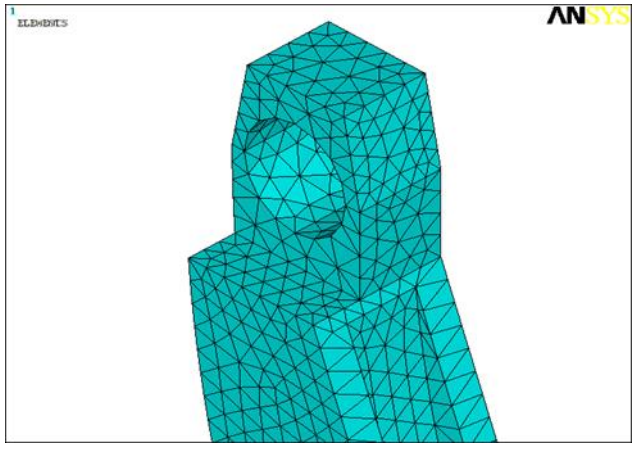

Figure (10): Mesh Design for Manacle Ring

#

8.0 Conclusion

The production technology rocket separation system is precise and complicated technology that includes accurate, complex design methods and high production technique, as it is one of the first

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attempts to be undertakes to enter the field of rocket industry. This study included the calculations operations, designing stages, different manufacturing process of the total separation system. This study faced some difficulties such as:

- The weakness of scientific infrastructure in the field in terms of paucity of references and scientific journals about this subject.
- The lack of experience in terms of design and manufacturing when dealing with separation system manufacturing.
- The lack of materials, technicians concerned into this subject.

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