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Comparison Study of Solid Rocket Motor Grain Geometries

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Abstract*— The major goal of this study is to design and build a solid rocket motor. Which is used as experimental sounding rocket. This paper mainly focus on fundamentals of rocket casing, solid propellant and grain cross sections. Based on the values and parameters the material are selected accordingly. SRM uses different grain cross sections to analyse higher burning rate (star, circular, double anchor). Design and analysis configuration using CATIA and open rocket software. This paper is manly concerned about to find high burning rate grain cross section.

Keywords: Design, Rocket, Software, Propellant.

I. INTRODUCTION

A. Background of Study

A solid rocket motor is a rocket motor that uses a solid mixture of chemicals as its Propellant. Solid rocket motors are commonly used in fireworks, military applications and widely used to generate thrust or impulsive force to impart a desired velocity to flight vehicle and to transport its payload to the intended destination. It has simple design, with the propellant mixture packed into a solid cylindrical casing with different grain geometry. These grain geometries give details about type of burning. Burning here are three type progressive, regressive and neutral burning? Once it ignited, the combustion of the propellant creates a high-pressure gas that is expelled through a nozzle, generating thrust. Solid rocket motors provide a high thrust-to-weight ratio and are often used as boosters to provide initial acceleration. Solid rocket motor is non-air breathing engine works on newton 2nd and 3rd laws. Solid motors are widely used because they are on demand, stored for a long period of time.(4,18)

B. Grain Geometry:

Grain geometry in the context of solid rocket motors refers to the physical shape and configuration of the solid propellant inside the rocket motor casing. The grain geometry plays a crucial role in determining the burning characteristics, thrust profile, and overall performance of the rocket. Several different grain geometries are used in solid rocket motors, each with its own advantages and applications. The choice of grain geometry, whether it's a double anchor, star grain, or another configuration, depends on the specific objectives of the rocket mission, such as payload requirements, altitude targets, and thrust-time profiles [8]. Each geometry offers a set of advantages and trade-offs that need to be considered in the context of the overall rocket design.(13)

C. Classification of Grain Geometry & their uses:

1. Star Grain Configuration: Star grains are a type of solid rocket propellant grain design that consists of multiple star-shaped channels or perforations within the grain. In star grains, designers can modify the burn rate by adjusting the shape, size, and orientation of the channels [9]. Star grains typically have a star-like or asterisk-like cross-sectional shape, with multiple radial channels or perforations extending outward from a central core [10]. These channels create a pattern that resembles the points of a star. It gives neutral burning because of that it used most

Figure 1: Star grain cross section using Auto CAD

2. Circular Grain Configuration: A circular grain geometry configuration is a specific design used in some solid rocket motors. Unlike star grains with their radial channels, circular grains have a more straightforward and uniform cross-sectional shape, resembling a cylinder or a simple disk [6]. Circular grains tend to burn more uniformly across their entire surface [5]. Since there are no radial channels or complex geometries, the burn rate is relatively constant, resulting in a smoother thrust profile. Because of their simplicity and uniform burn characteristics, circular grains are often chosen for applications where a predictable and consistent thrust profile is desirable, such as in sounding rockets, fireworks, or other specialized application.

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Figure 2: Circular grain cross section using Auto CAD

3. Double Anchor Grain Configuration: A "double anchor" grain is a specific type of grain geometry used in solid rocket motors. This design is characterized by having two distinct, symmetrical channels or perforations in the solid propellant grain that resemble the shape of an anchor, hence the name “double anchor” [2]. The grain is symmetrical with respect to its central axis. It has two identical channels that are usually positioned opposite each other, creating a balanced and symmetric burning pattern. Double anchor design can promote efficient combustion by ensuring that the propellant burns evenly from both channels, minimizing the likelihood of unburned propellant residues. It gives regressive type of burning

Figure 3: Double anchor grain cross section using Auto CAD

4. Casing: Combustion takes place in the casing known as combustion chamber the casing must withstand the high temperature and pressure which is created by igniting the solid propellant. Material like titanium, aluminium T0T6, Austenitic stainless steel. These material are highly capable for heat resistance up to minimum 650 degree Celsius(18)

Figure 4: Stainless steel casing

5. Nozzle: A nozzle is a tube of varying cross-sectional area (usually asymmetric) aiming at increasing the speed of an outflow, and controlling its direction and shape Two types of Nozzle, Converging nozzles and Converging-Diverging nozzle. The highly combusted gases exit towards the nozzle where the chemical energy is converted to kinetic energy. Nozzle exhaust the gases with high velocity. Nozzle bears the high temperature and pressure because energy transformation takes place. Mild steel is the material used for nozzle(18)

Figure 5: Mild steel nozzle

6. Propellant: A propellant is a mixture of chemicals which burns rapidly when ignited. Major components of propellant are oxidizer and fuel. Oxidizer provides oxygen for fuel burning. The ratio of these two components alters the burn rate of propellant. The propellant used in solid rocket motors is a mixture of fuel and oxidizer. It is typically made of powdered metals, such as aluminium, combined with a powdered oxidizer, such as ammonium perchlorate. This mixture is then bound together with a polymer binder. When ignited, the propellant undergoes a chemical reaction, releasing a large amount of energy in the form of hot gases, which propels the rocket forward. Propellant used in the experiment is Rocket candy and the most common propellant used in SRM is Hydroxyl Terminated Polytubadiene (1,7,11,18)

7. Rocket candy: Rocket candy" is a colloquial term for a type of homemade or amateur rocket propellant known as "sugar propellant" or "sugar rocket propellant. It is called "candy" because of its appearance and texture [3]. Rocket candy propellant typically consists of a mixture of powdered sugar (sucrose) and a powdered oxidizer, most commonly potassium nitrate (KNO3). The primary ingredients are powdered sugar (fuel) and potassium nitrate (oxidizer). The ratio of sugar to potassium nitrate can vary, but a common starting point is a 65:35 ratio by weight(11,14,17).

II. DESIGN PROCEDURE

Casing: Casing is the first design part to assemble the grain configuration into the casing. Using open rocket software the design has made (18)

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Figure 6: 2D casing using open rocket

Figure 7: Modelling casing using open rocket

Length of the casing: 24.5cm
Diameter of casing: 5.5cm
Material: Stainless steel and mild steel

Grain geometry:

Considering the same diameter with similar area. CATIA is used for designing the grain [12]

Grain calculation:

Table 1: Calculation of grain area

Sr. No.	Type of grain	Formula used	Obtained Area
1	Star Grain	Formula of regular hexagon is = 3V3/ 2 x s2. /A (cone)= n r (s + r)	36.1424
2	Double-Anchor Grain	Area of a rectangle = a* b	36.2743
3	Circular Grain	for hallow circle area of a circle= n r п Pi(r1-r2)	34.5575

Model:

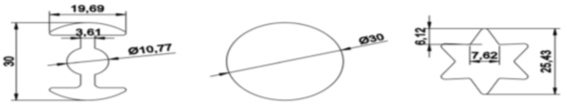

Figure 8: Grain area and dimensions

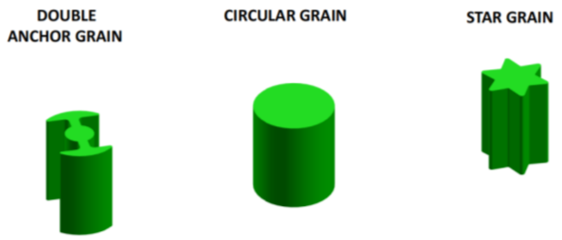

Figure 9: 3D Grain cross section using Auto CAD

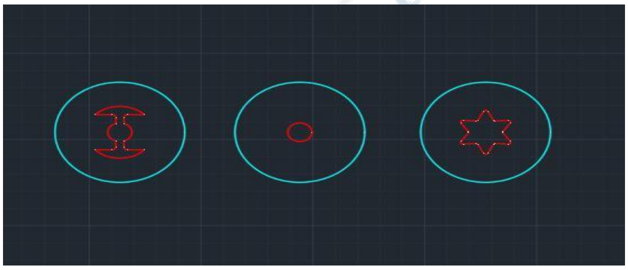

Figure 10: 2D Grain geometry using Auto CAD

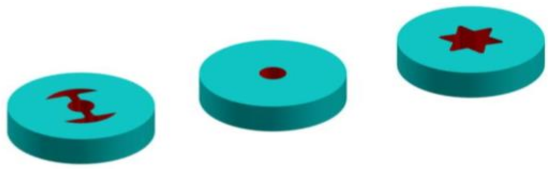

Figure 11: Grain geometry

We are supposed to study the different burn rate on different shape with similar area so considering these 3 different shapes of grain. Let to know us which produce the high burn rate

Static Test bed stand: A static test bed for rockets is a specialized facility where rocket engines and related components are tested under static (stationary) conditions [15]. These tests are crucial for evaluating the performance, safety, and reliability of rocket propulsion systems before they are used in actual space missions. Here are some key aspects of a static test bed for rockets [16]. The primary purpose of a rocket static test bed is to test rocket engines. Rocket engines are attached to a test stand, and the propellant (fuel and oxidizer) is burned within the engine while it remains stationary. Sensors and load cells are used to measure the force exerted by the engine during the test. This data helps engineers verify that the engine is producing the expected amount of thrust [17]. The measurement devices we often use in test bed are: pressure sensor, humidity sensor, Arduino uno etc.

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Figure 12: Static test pad using Auto CAD

Static test bed doesn't need specific dimensions as per your rocket length, width and specifications you can consider it roughly

III. CONCLUSION

We understand that burn rate determines that how fast a propellant burns with different types of grain geometry. Also different grain area effect the burn rate and thrust of the rocket. We conclude that using various grain cross section in a solid rocket motor star grain geometry has produce the best burn rate and thrust vs time graph with neutral burning

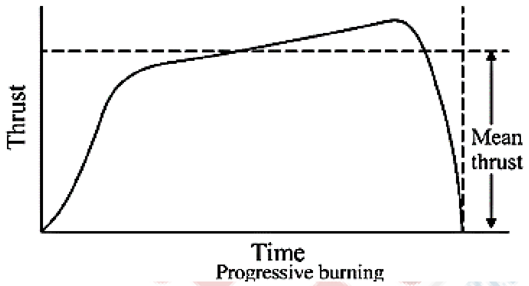

Figure 13: Circular burn rate

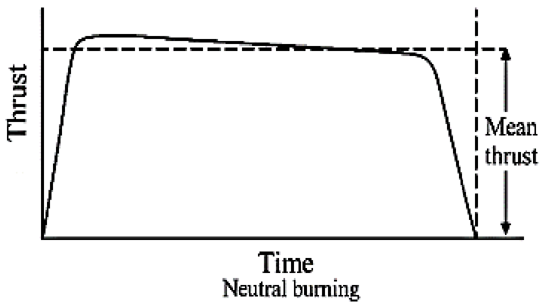

Figure 14: Star burn rate

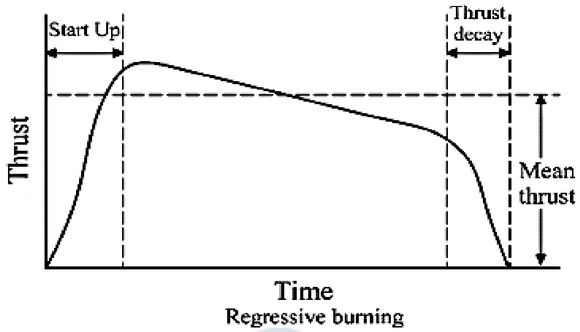

Figure 15: Double anchor burn rate

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