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Investigation of Solid Propellant Rocket Engine – An Theoretical Approach

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ABSTRACT
Solid propellant rockets are mostly playing important role in assisted-takeoff missiles, projectiles and a number of other applications. For small rocket missiles solid propellant rocket is widely used because of its suitability and performance along with the geometrical orientation. But when we consider high range rocket missiles, a solid propellant rockets are not suitable, because of its low specific impulse and high speed. A solid propellant rocket also have a disadvantages of limitation in burning duration. Difficult to control the burning of the propellant as well as cooling of the thrust chamber. There is no universal well-defined procedure or design method for making a design of solid propellant rocket engine. Even though we followed some common concepts while making a design of solid propellant rocket engine, there also some critical problems occur. In order to rectify such a problems we should take almost care on propellant grain and grain configuration and propellant ingredients. In this paper we discuss in detail about analysis of solid propellant rocket engine though a theoretical approach. The operation and design of rocket engine is purely depends on the combustion characteristics of the propellant, its burning rate, burning surface and grain geometry.

Keywords: Propellant burning rate, Grain geometry, Burning surface, Thrust coefficient.

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I. INTRODUCTION

Solid propellant is the combination of solid fuel (plastic or resin material) and oxidizer(nitrates).
Both the solid fuel and oxidizer are homogenously mixed and packed in side the shell. Historically, solid propellant rocket engines are designed with no moving parts. This may be true for some cases, but some rocket designs include movable nozzles and actuators for vectoring the line of thrust relative to the rocket axis in current scenario. The operation of the solid propellant rocket engine is depends on grain configuration, burning rate, combustion characteristics and nozzle properties.
The main objective of present work are:
a) To study the complete operational phenomena of solid propellant rocket engine
b) To study the complete structural design of solid propellant rocket engine along with its components.
c) To find the parameters, which are necessary to analyze a rocket with aid of theoretical approach.

1.1 SOLID PROPELLANTS

Generally solid propellant rocket engine propellant can be classified into two categories, namely double base (DB) propellants form a homogeneous propellant grain, usually a nitrocellulose (NC*), a solid ingredient which absorbs liquid nitroglycerine (NG) plus some percentage of additives. Composite propellants form a heterogeneous propellant grain with aid of oxidizer crystals along with a powdered fuel.

1.2 GRAIN CONFIGURATION

The grain is the solid body of the hardened propellant and accounts for 82 to 94% of the total engine mass. Engine performance characteristics can be evaluated by both the propellant material and geometrical configuration of the grain. The propellant grain is a cast, molded, or extruded body and its appearance is look like a rubber or plastic. There are two methods of holding the grain in the case, Cartridge-loaded and Case bonded grain.
Progressive Burning: thrust, pressure and burning surface increase with respect to burn time.
Regressive Burning: thrust, pressure and burning surface decrease with respect to burn time.
Neutral Burning: thrust, pressure and burning surface area approximately constant with burn time.

1.3 STRUCTURAL DESIGN

The structural analysis begins when all loads can be identified and quantified. The kind of loads and timing of these loads during the life of a solid propellant rocket engine have to be analyzed for each application and every rocket. Although ignition and accelerations usually cause high stresses and strains. The maximum stress and strains can be accepted by the propellant under various conditions. The failure criteria are derived from cumulative damage tests, classical failure theories, actual rocket failures, and fracture mechanics.

1.4 COMBUSTION

The combustion chamber of a solid propellant rocket is a high pressure tank containing the entire body of solid mass of propellant or grain. Combustion takes place from the surface of the grain. The rate of generation of gaseous propellant is equal to the rate of consumption of solid material. The various polymeric binders used in composite propellants are less well characterized, and their combustion process vary, depending on the binder type, heating rate and thrust chamber pressure. Solid propellant ignition consists of a series of complex rapid events, which start on receipt of a signal (usually electric) and include heat generation, transfer of the heat from the igniter to engine grain surface, spreading the flame over the entire burning surface area, filling the chamber free volume (cavity) with gas and elevating the chamber pressure.

1.4.1 COMBUSTION INSTABILITY

When instability occurs, the heat transfer to the burning surfaces, the nozzle, and the insulated case walls is greatly increased , the burning rate, chamber pressure, and thrust usually increase; but the burning duration is thereby decreased. Undesirable oscillations in the combustion cavity propellant rocket engine is a continuing problem in the design, development, production, and long term retention solid propellant rocket missiles. The bulk mode or chuffing mode is not a wave mode and it occurs at relatively low frequencies and the pressure is uniform throughout the volume.

1.5 NOZZLE

The supersonic nozzle provides for the expansion and acceleration of the hot gases and has to withstand the severe environment of high heat transfer and erosion. The following type of nozzles is widely in solid propellant rocket engine.

a) Fixed nozzles: fixed nozzles are generally not submerged and do not provide thrust vector control.

b) movable nozzles: movable nozzles can provide pitch and yaw control and two are needed for roll control. Movable nozzles are typically submerged and use a flexible sealed joint or bearing with two actuators.

c) submerged nozzles: A significant portion of the nozzle structure is submerged within the combustion chamber or case.

d) extendible nozzle: the extended nozzle improves specific impulse by doubling or tripling the initial expansion ratio, thereby significantly increasing the nozzle thrust coefficient.

II. INDENTATIONS AND EQUATIONS

The following formulas were used to find out the parameters, which are necessary to investigate the entire process of the solid propellant rocket engine.

The thrust produced is given by

$F = m^*C_j + (P_e - Pa) A_e$ (1)

If q is the heat supplied in the form of chemical energy per unit mass of propellant, we get

$Q = C_p(T_{02} - T_{01})$ (2)

Specific impulse of a rocket engine is given by

$I_{sp} = C_j / g$ (3)

Specific Propellant Consumption is given by

$SPC = W_P / F$ (4)

Weight floe coefficient is given by

$C_w = W_p / P_o A^*$ (5)

Thrust coefficient is calculated through

$C_F = F / P_o A^*$ (6)

Characteristic velocity of a rocket is given by

$C^* = C_J / C_F$ (7)

III. FIGURES AND TABLES

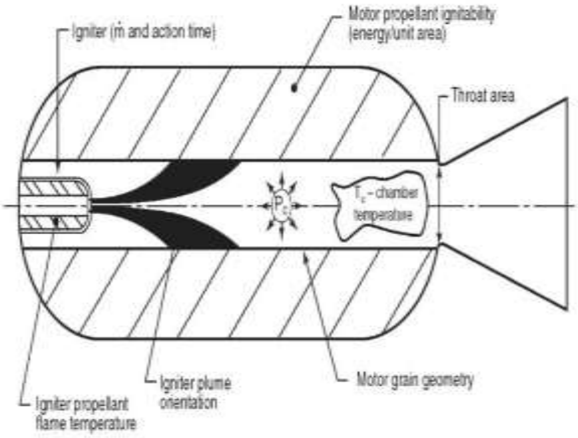

Figure 1. Schematic of solid propellant rocket engine

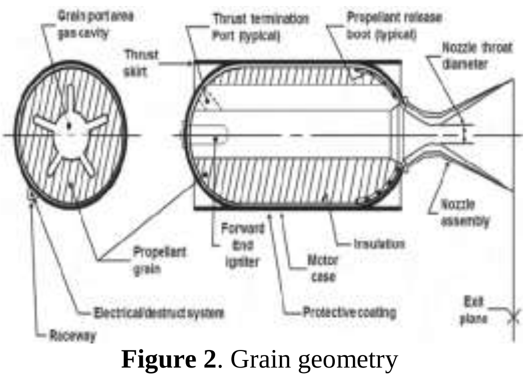

Figure 2. Grain geometry

Both the thrust coefficient and specific impulse of a solid propellant rocket engine can be evaluated with aid of following data, as example.

S.No	Parameter	Quantity
1	temperature	3100 K
2	Molecular mass	23 Kg/Kmol
3	pressure	7 Mpa
4	Ambient pressure	0.1 Mpa
5	Specific heat ratio	1.4

Table 1. Inputs for Calculation

From the above inputs, after making a calculation by using standard above said formulas, we have the following results.

S.No	Parameter	Quantity
1	Characteristic velocity	1569.59 m/s
2	Exit mach number	3.37
3	Exit pressure	191.25 Kpa
4	Ratio of exit to throat area	8.122
5	Thrust coefficient	1.538
6	Exit velocity	2411 m/s
7	Specific impulse	245.76 S

Table 2. Final Results

IV. CONCLUSION

From the above theoretical work we can concluded the following aspects as a result of a present work.

1.when the solid propellant rocket engine is in motion condition, decrease of speed of the engine is not possible, the specific impulse of a solid propellant rocket engine is low compare to the liquid propellant rocket engines. Nozzle erosion is unavoidable duo to the presence of solid particles in the high temperature and high speed gases.

2. The solid propellant rocket engine do not require any feed systems, because it do not have any moving parts. It will also cause the less vibration. The overall shape and size of the rocket is purely depends on the nature of the propellant used. However we do not have any consolidated design criteria or design method for formulating the consolidated solid propellant rocket engine.

3. from the result of a present work, the specific impulse of a solid propellant rocket engine is moderate compare to liquid propellant. Still we are in the position to improve the exit velocity of the engine in future in the case of solid propellant rocket engine. Its also found that, the solid propellant rocket engine is best suitable for short range applications.

4. The function of the nozzle is to convert the pressure energy of the gas into kinetic energy. After completing the operation of the engine high temperature and high velocity gases are expand in the nozzle section. During the nozzle operation the temperature of the nozzle also increases. In this regard nozzle to cooled after operation, but cooling of nozzle is not possible in the case of solid propellant rocket engine.

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