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Development Rocket Performance of 107mm Using Composite Propellant

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Abstract

The design of 107mm solid rocket motor using hydroxyl-telechelic poly-butadiene (HTPB) propellant to increase the rocket performance of 107mm and details study of the internal ballistic affecting performance of the motor using solid propellant will be analyzed. Both approaches analytical and experimental have been used to calculate the internal ballistic parameters and performance. This objective of this study will be achieved by the grain configuration design, propellant formulation design, small batches of propellant and firing test. The basic solid rocket motor is the double base propellant. In this study we used composite propellant (HTPB) instead of double base, the solid rocket motor composite propellant designed by two formulation. First RMD-107-1 formulation giving low burning rate 11.8mm/s, this result is not suitable for requested design. Second RMD-107-2 formulation giving high burning rate 31.41mm/s. This formulation high burning rate is adopted according to the requirement for our design. Six degree of freedom (6DOF) will be used to calculate the range of tow motors. Original motor and modified one, experimentally test carried for two motors. The original motors represent the performance that was designed for double base propellant. Modified motor represent the performance for modified grain propellant which was design by using composite propellant. Therefore the original motor and modified will be designed with same combustion chamber and nozzle.

Keywords: *Thrust, Pressure, solid propellant, Internal Ballistic, Solid Rocket Motor.*

1. Introduction

The 107mm rocket motor is such a ground-base tactical device used for attacking the stationary ground target, with the maximum range of 7km and considered one of the strongest rockets from destruction, which rotates around its axis as a result of the movement of gases out through the nozzle with an angle of 20o. The rocket motor is an important part of missile and spacecraft technical compositions, and it is the power source for the missile weapon system or spacecraft to arrive its pre-set target and bring its operational ability into play. The propellant is the material providing energy power for the motor. A propellant system can be described as a balanced source of potential energy containing the necessary ingredients for conversion of this energy into kinetic energy.

The initial burning start from the internal surfaces of perforation. The internal cavity area increase while the propellant consumed by burning so the generated gaseous flows through the supersonic nozzle (1).

1.1 Solid Rocket Motor

The solid rocket motor components show in figure (1) as following:

- Motor case
- The Nozzle
- Rocket Propellant

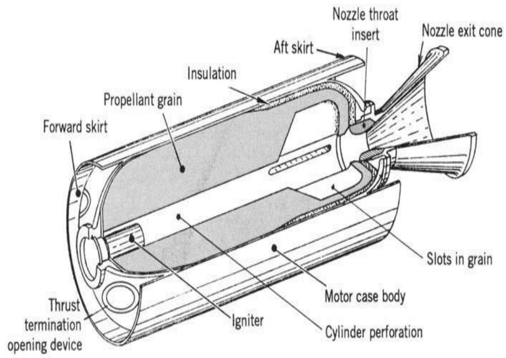

Figure 1: Solid Rocket Motor (SRM)

1.2 Composite Propellants

The solid composite propellant which is used most frequently currently. It is composed of ammonium perchlorate (Ap) acting as the oxidizer, aluminium powder (AL) acting as the fuel agent, hydroxyl-terminated polybutadiene (HTPB) acting as the adhesive agent and toluene diisocyanate (TDI) acting as the curing agent.
The HTPB solid composite propellant is such a propellant as widely applied for its outstanding comprehensive performance. In order to achieve the high burning velocity, it is required to use the liquid catalyst of tert-butyl ferrocene (2).

1.3 Chamber Pressure

When the propellant burn inside the combustion chamber the pressure will increase gradually up to all propellant will ignite and burn and this pressure is called chamber pressure. So the chamber pressure is not constant during the whole operation for rocket motors.
The chamber pressure is the directly affecting on the thrust of the rocket motor, so it is most useful for the designers to reach the thrust level required.
The chamber pressure behavior across the time of burning of the solid propellant grain gives full information about the internal processes inside the combustion chamber. The pressure time (PT) curve Figure (3) shown the pressure behavior from the starting of the rocket motor to the peak point and decaying to the equilibrium condition (3).
It consists of the following main parts:

- The initial pressure rise part (O – A).
- Stabilization of pressure part (A – B).
- Pseudo-equilibrium pressure part (B – C).
- Exhaust part (C – D).

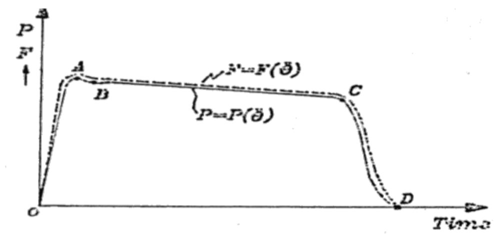

Figure 2: PT

1.4 Total Impulse

The total impulse (I_t) of a rocket is the product of thrust times duration over the motor burn time. The total impulse is proportional to the total energy generated by the propellant in a propulsion system.

1.5 Thrust

The thrust is reaction force on the rocket structure which generated by the propulsion system of the rocket, so the rocket move through the space.

1.6 Specific Impulse

The Specific impulse is the change in momentum or the total impulse per unit of propellant consumed (5).

2 Model Description

The description of the 107mm rocket configuration as below is showing in figure (3)

1 Rocket motor chamber.
2 Nozzle assembly.
3 Rocket propellant.

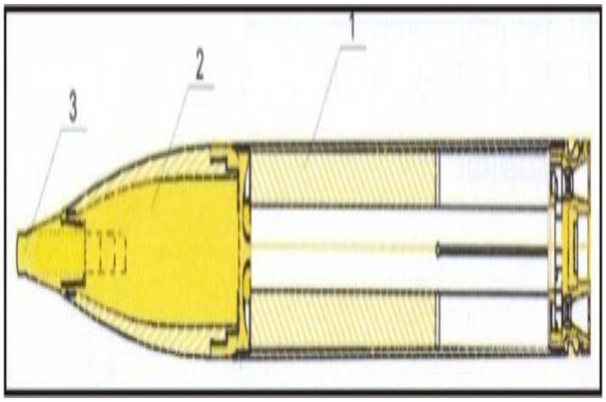

Figure 3: The 107mm rocket configuration

2.1 Technical data

The rocket caliber is 107 mm
Propellant double base grain with round hole (7 pcs).

Length of the rocket with the fuse	836mm.
Weight of the rocket with fuse	18.85 kg.
Propellant thrust	9180N
Max pressure	12.5Mpa
Max rocket velocity	377m/s
Burning time	0.54 sec
Tube length	478.5 mm
Tube thickness	4.5 mm

2.2 The 107mm nozzle

The motor contains propellant that in effect of its fast burning and passing resulted gases through the nozzle holes, the rocket moves toward. The nozzle is screw to rear part of the motor tube and has six special holes for gas exit, so the resulted gas of burning charge comes out through the nozzle holes, due to special location of the nozzle holes (for exciting gases). Therefore rocket will spin on its longitudinal axis during flight.

Table 1: Technical characteristic of the 107mm original rocket motor

TECHNICAL CHARACTRISTIC	VALUE	UNITS
Temperature range	20	C°
Propellant mass	4500	G
Burning time	0.54	S
Total thrust impulse	7.31	KN.s
Specific impulse	2500	KG.S
Pressure impulse	12.5	MPa

2.3 Design of propellant formula

The selected propellant is the HTPB solid composite propellant which is used most frequently currently. It is composed of ammonium perchlorate (Ap) acting as the oxidizer, aluminum powder (AL) acting as the fuel agent, hydroxyl-terminated polybutadiene (HTPB) acting as the adhesive agent and toluene diisocyanate (TDI) acting as the curing agent.
The other constituents include: diisooctyl sebacate (DIOS) acting as plasticizer; ammonium oxalate (AO) acting as the burning rate modifier.
The design of propellant formula made on the base of the operating characteristic of107mm.
In order to achieve the high burning rate, the HTPB solid composite propellant is such a propellant as widely applied for its outstanding comprehensive performance.

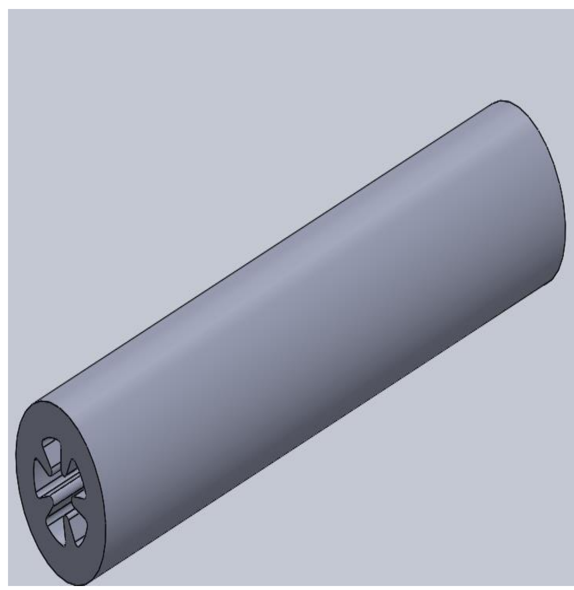

Figure 4: The 107mm propellant grain configuration

3 Results And Discussion

3.1 (RMD-107-1) formulation

The low burning rate formula containing 24, 24 and 23.5 % of grinded ammonium perchlorate AP (140-100), AP (80-60) and AP (10-5) respectively and the presence of 15% aluminum added to give good specific impulse. Table (2) shows the ingredients and their amount in this formulation and tables (3 and 4) shows the results of formulation.

Table 2: (RMD-107-1) formulation ingredients and percentage

NO	MATERIAL CODE	AMOUNT(g)	PERCENTAGE
1	HTPB	386	8.489
2	MAPO	4.6	0.102
3	DOS	130.9	2.909
4	TBFe	90	2
5	TDI	22.8	0.5
6	AP(80-60)	607.5	24
7	AP(140-100)	810	24
8	AP(10-5)	1710	23.5
9	AL	720	15
10	x-585	22.5	0.5
11	H	6.3	0.14
12	Hx-103	4.5	0.1
13	BX	90	2

Table 3: The result of Internal Ballistic Formulation (RMD-107-1)

r	11.865
Isp	1829.1
C*	1600.

Table 4: The result of Mechanical and Physical properties(RMD-107-1):

Density	1.73	Extensibility	27.79
Hardness	50	Tensile	0.757

3.2 (RMD-107-2), Formulation Results

The low burning rate formula containing 12,16 and 41% of grinded ammonium perchlorate AP (140-100), AP(80-60) and AP(10-5) respectively in this formulation to increase the percentage of fine AP (10-5) and decrease the other size to improve burning rate, added 16% aluminum to improve the specific impulse. Table (5) shows the ingredients and their amount in this formulation.

The formula (RMD-107-1) comparing to (RMD-107-2) is containing less amount of fine grinded ammonium perchlorate and with the same amount of aluminum approximately.

Table 5: (RMD-107-2) formulation ingredients and percentage

NO	MATERIAL CODE	AMOUNT(g)	PERCENTAGE
1	HTPB	386	8.489
2	MAPO	4.6	0.102
3	DOS	130.9	2.909
4	TBFe	90	2
5	TDI	22.8	0.5
6	AP(80-60)	607.5	12
7	AP(140-100)	810	16
8	AP(10-5)	1710	41
9	AL	720	16
10	x-585	22.5	0.5
11	H	6.3	0.14
12	Hx-103	4.5	0.1
13	BX	90	2

Table 6: Internal ballistic performances

r	31.41
Isp	2313.8
C*	1120.6

Table 7: Mechanical and physical properties

Density	1.73	Extensibility	27.79
Hardness	50	Tensile	0.757

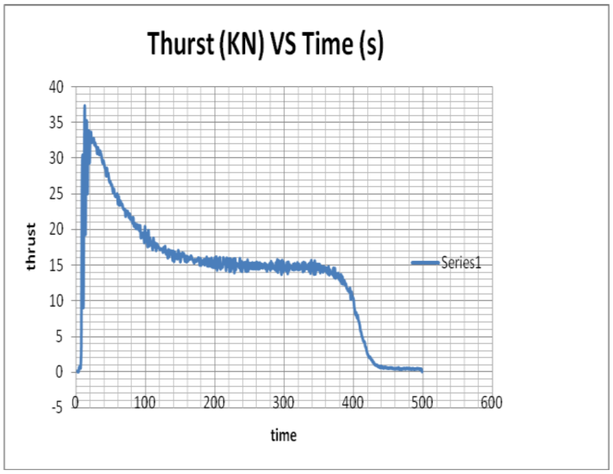

Figure 5: Thrust time curve for original motor

Table 8: Thrust time curve data for original motor

TIME(s)	THRUST(KN)
0	0
0.009	18538.7
0.013	24017.64
0.021	20765.9
0.038	18701.86
0.098	15331.5
0.184	13827.9
0.291	13384.59
0.449	13472
0.488	11354.67
0.54	0

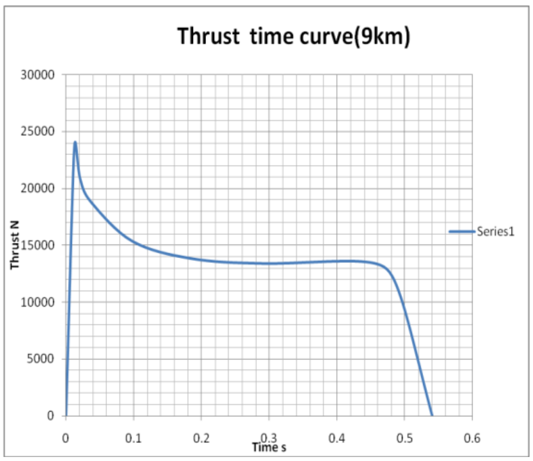

Figure 6: Thrust time curve for modified motor

Table 9: Thrust time curve data for modified motor

TIME(s)	THRUST(KN)
0	0
0.005	0.7202
0.018	33.7648
0.023	32.2127
0.031	30.6273
0.08	21.4893
0.176	15.9461
0.32	14.3302
0.451	0.4721
0.472	0.4167
0.498	0.3252
0	0

Table 10: 6(DOF) Program result for original motor

T	DOMET	H	Z	V	TETA
(s)	(m)	(m)	(m)	(m/s)	(deg)
0.000	0.0	0.0	0.0	0.0	24.0
0.047	0.8	0.4	0.0	41.1	24.0
0.051	1.0	0.4	0.0	44.7	23.2
0.056	1.2	0.5	0.0	49.1	21.6
0.061	1.4	0.6	0.0	53.4	21.7
0.066	1.7	0.7	0.0	57.6	23.2
0.071	2.0	0.8	0.0	61.8	23.1
0.076	2.3	1.0	0.0	66.0	22.1
0.081	2.6	1.1	0.0	70.1	22.8
26.977	7010.9	50.1	277.1	244.9	-29.8
27.027	7021.5	44.0	278.0	245.0	-29.9
27.077	7032.0	37.9	278.9	245.0	-30.0
27.127	7042.6	31.8	279.8	245.1	-30.1
27.177	7053.2	25.7	280.7	245.2	-30.2
27.227	7063.7	19.5	281.6	245.2	-30.3
27.277	7074.3	13.3	282.5	245.3	-30.4
27.327	7084.8	7.1	283.4	245.4	-30.5
27.377	7095.4	0.9	284.3	245.4	-30.6

Table 11: 6(DOF) Program result for modified motor

T	DOMET	H	Z	V	TETA
(s)	(m)	(m)	(m)	(m/s)	(deg)
0.000	0.0	500.0	0.0	0.0	48.0
0.041	0.6	500.7	0.0	53.2	48.0
0.045	0.8	500.8	0.0	59.3	46.7
0.050	1.0	501.1	0.0	66.6	45.5
0.055	1.2	501.3	0.0	73.6	47.2
0.060	1.5	501.6	0.0	80.4	46.7
0.065	1.8	501.9	0.0	86.9	46.5
0.070	2.1	502.2	0.0	93.2	47.2
0.075	2.4	502.6	0.0	99.3	46.6
0.080	2.7	503.0	0.0	105.0	47.3
0.085	3.1	503.3	0.0	110.6	46.8
0.090	3.5	503.8	0.0	115.9	47.2
48.954	8900.6	594.5	908.6	256.4	-57.0
49.004	8907.4	583.8	910.2	256.6	-57.0
49.054	8914.2	573.0	911.8	256.8	-57.1
49.104	8921.0	562.2	913.4	257.1	-57.2
49.154	8927.8	551.4	915.0	257.3	-57.2
49.204	8934.6	540.6	916.6	257.5	-57.3
49.254	8941.4	529.8	918.2	257.7	-57.3
49.304	8948.2	518.9	919.8	258.0	-57.4
49.354	8954.9	508.1	921.5	258.2	-57.5

4 Discussion

The adjusted of propellant formulation is a part of the optimization process by changing in the weight fractions of related ingredients. Since the cure reaction is dependent on the equivalent ratio.
The burning rate depends on the percentage of ammonium perchlorate when we increase the fine size where the burning rate was increased.
The increase in the percentage of aluminum the specific impulse was improved.
Table (3) shows the result of formula (RMD-107-1) the burning rate is 11.8 mm/s, that is not suitable for design, the specific impulse 1829.1 s and density 1.73Kg/m3 so the mechanical properties was found good
Table (6) shows the result of formulation burning rate (RMD-107-2). They found burning rate is 31.41mm/s which is the highest burning rate compared to other formulation (RMD-107-1) by 19%, the specific impulse 2313.8 s and density 1.76 Kg/m3.
Figure (5) represent the thrust time curve for original motor, this curve achieved by static test, thrust starts from minimum and increase gradually to maximum thrust 24.01KN and decreased at the tail phase when propellant consumed. From the curve the total impulse found 6.97 KN (integral area under the curve), the burning time is 0.54s.
Figure (6) represent the thrust time curve achieved by modified motor test in which 107motor designed with the same combustion chamber and the same nozzle, which design by using composite propellant. The total impulse found 7.31 KN, maximum thrust was found 37.26 and burning time is 0.498 S.
table(10) shows the data range resulted from (6DOF) program, the range of the original motor was 7.09KM and modified motor give a range of 9KM , which is greater than the rang of the original motor by 2KM which was the best design.

5 Conclusion

The main parameter requirement design taking from the original rocket motor, thrust, burning time, burning rate and theoretical specific impulse therefore estimate the suitable grain configuration according to requirement design.
Star grain is the best type of grain configuration of composite propellant that suits the 107mm rocket motor, according to the requirement, thrust, action time, because need one stage and high thrust with low burning time
The results of the internal ballistics for new 107mm motor design showing better than the original motor results provided by the final static tests.
The results of internal ballistics calculation show an agreement with experimental results provided by the final static test result.
The design of the propulsion system in this study started by using star grain configuration, it is gave more loading factor and this means higher total impulse. So it is reasonable than the other configuration.
The design of modified motor, the propellant burn from inside surface for 0.54 s to provide 7.31 KN.s total impulse with rang of 9km.

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