International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 9, Issue 5, Oct 2019, 715–724

PYRO BASED SYSTEMS IN FIN LOCKING MECHANISM FOR MISSILE APPLICATIONS

D. SMITHA[1], VINAY KIRAN KOLANU BIKSHA[2], D. SAI PRASAD[3] & R. VENKATESHWAR[4]

[1]Associate Professor, Department of Aeronautical Engineering, MRCET Hyderabad, Telangana, India

[2,4]Departmentt of Mechanical Engineering Vignan Bharathi Institute of Technology, Hyderabad, Telangana, India

[3]Defence Research and Development Laboratory, Defence Research and Development Organization, Kanchanbhag, Hyderabad, Telangana, India

ABSTRACT

A Pyro based mechanism is used in flight vehicles for control of fins. Here, a Pyro pin puller based lock and release mechanism has been designed to lock (arrest the movement of) the control fins when the missile is under carriage condition and to unlock when the missile clears the nose tip of aircraft after launch. This is a very critical mechanism as far as the launch of the missile is concerned. The dimensions of the individual components are derived from the classical design approach. The modelling of the components has been done by using solid works and the analysis is carried out using ANSYS.

KEYWORDS: Control Fins, Pyros & Mechanisms

Received: Jul 16, 2019; **Accepted:** Aug 07, 2019; **Published:** Sep 23, 2019; **Paper Id.:** IJMPERDOCT201963

Original Article

INTRODUCTION

Currently in space and defence applications, pyro operated mechanism is widely used. These devises are used in separation mechanisms and flow control values. These are highly reliable systems and their usage improves the reliability of the overall system. In defence applications one of the area where these pyros widely used in holding the control surfaces of air-launched weapons. One such system developed is Fin Locking Mechanism (FLM). The above technique is also used for holding the fins in locked condition at the time of launch and unlocking them after attaining safe separation distance.

The configuring of design is carried out using CAD software (Solid Works). This is one of the widely used and user friendly software. The complete FLM system is modelled using this software and analysis is carried out using ANSYS software. The system reliability is verified by carrying out the actual tests on the ground.

Purpose of the Study

Controls surfaces are most commonly used in missile applications, these surfaces are most popularly known as FINS in the missile systems. These fins are realized by various methods in the past and lot of research is being carried out in this area since the beginning of missile systems. The control surfaces of missile system exiles aerodynamic loads, a FLM is used to arrest their movement. The only issue with the Fin locking mechanism lies in Pyro cartridge which is quite high in cost and the standard Pyro cartridge are available in the global market. The main reason for focusing on the Pyro cartridge is due to the sensitive nature of the circuit that affects total performance of the Fin locking system. Various studies are being carried out to improve the Pyro techniques as in the research carried out by Danali S. M [3].

In this context, the proposed work carried out in this project deals with a detailed study on the Fin locking mechanism and functioning of the system. At the same time this research allows to understand the design parameters of a mechanism that suits for the applications of missiles.

LITERATURE SURVEY

In the design of mechanisms for locking fins or control surfaces two fundamental designs are available, one is mechanisms operated by Pyro devices and another one is solenoid actuators. Selection of mechanism design is based on volume available in the product, power requirements, repeatability and reliability. All around the world designers prefer designing these mechanisms operated by Pyro devices. Though Pyro operated mechanisms are single shot devices they are reliable. In mission mode projects reliability is given priority than repeated usage of the system.

Previous Research on FIN Locking Mechanismons

Similar work has been done by Seung-gyo Jang, Hyo-nam Lee and Jong-yun Oh (2014) they designed the mechanism for locking the missile in the canister. In this design each plunger operation needs an individual pyro.

Similar Research work has been done by Dana D. Hawthorne and HR Textron (2006) they designed locking devices which can be operated by solenoid release pins. In this design a locking device with solenoid device includes housing, plunger axially slidable member for biasing the plunger. Solenoid coil disposed in the housing around the plunger, for inducing a magnetic force move the plunger against the biasing member Such that the balls are movable radially inward into the recesses thereby releasing the locked member.

Similar Research work has been carried out by William W. Hsu, Glendale; Duncan D. Bragg, Simi Valley,(2001) they designed fin locking mechanism which can operated by a restraining device and spring. Upon a command Signal from a controller, preparatory to launch, a restraining device holding the Slide is removed and a Spring commences movement of the Slide towards a position which will take the links past their dead center position upon which additional Springs which loaded around each of the pins are activated to positively move the slide and extract the pins from the openings in the fins.

The present invention is directed to a locking mechanism operated by a Pyro (Electro Explosive Device) for use on a missile having a moveable control fins extending from an outer surface thereof, the locking mechanism includes a locking pin for each of the moveable control fins which is adapted to extend through the outer surface of the missile into an opening in the control fin to retain the control fin in a fixed position prior to launch. When control surface are to be unlocked command is used to fire the Pyro and high pressure gases excess pressure on plunger and plunger retracted down by shearing the shear pin.

Basic Function of Mechanism

In operation of a fin locking mechanism constructed in accordance with the principles of the present invention, the missile would be assembled with the fins in their locked position. That is, upon assembly of the missile the fins would be attached to the members and would then be positioned such that the opening would be immediately adjacent the opening in the surface through which the pin would extend. The restraining mechanism would then be engaged to assure that the plunger remained in its pin extend position. After assembly of the fins in their locked position, missile will be loaded upon the aircraft and the aircraft would take flight toward the predetermined area so that it may accomplish its mission. Upon detection of the desired target whether it be a surface target or an air target, depending upon the particular mission of the missile. The desired time of

launch an appropriate control signal from the controller would be applied to the Pyro cartridge releasing the restraining device from engagement with the slide member.

When the unlock command is received and the Pyro cartridge is activated to release high pressure gas towards the plunger. As soon as the plunger commences to move towards the downwards shear pin immediately shear it off. The high pressure gas generate the greatest amount of force are activated and move the plunger forcibly downward. Since plunger are coupled inside the cylinder then simultaneously moved thereby positively extracting the pins and unlocked the fins. In this condition the control signals received from the guidance system in the missile can appropriately start functioning cause the fins to move appropriately to control the flight path of the missile.

DESIGN ASPECTS OF FLM SYSTEM

Typically, the fins of a missile must be locked during transportation on an aircraft or other launch vehicle. However, at launch time, they must be quickly unlocked to be ready for missile flight. For example, a missile carried on an aircraft has its fins locked prior to launch. When the pilot is ready to fire the missile, a signal is sent from the cockpit which starts the missile's battery. When the cockpit has confirmation that the missile is powered, it signals the missile's fins to unlock and wiggle to verify function. When fin release and function is confirmed, the cockpit signals the missile launcher to unlock and launch the missile. In a combat situation, where time is critical, it is essential that the fins unlock as quickly as possible.

Prior approaches include a complicated system employing a gas generator. To affect fin release, this prior system collects gas and distributes it through a manifold to each fin piston, which compresses to release the fin. This system has many parts and is slow, taking on the order of 70 milliseconds to unlock the fins. Another prior approach utilizes a shear pin which fractures to unlock the fins. Thus, a need remains in the art for a less complex, more reliable system which can lock the fins of a small diameter missile yet quickly unlock them for launch.

Basis of Design

Basically design is made depend on the volume of mating component. Initially the basic dimensions of the individual components are derived from the classical design approach the modeling of the component as per the derived basic dimensions. Some of the basic parameters are to be considered for design the mechanism. Sizing of individual components are taken in to consideration by checking with mating part. Total four control surfaces are assembled in missile so design should do with less complexity. The design is made to hold two control surfaces for each FLM unit. Generally this mechanism comes under Pin-Puller type. Design parameters are to be considered carefully for designing pin puller type mechanisms.

These FLM units consist of two cylinders, two plunger pins and two shear pins. Plunger pin and shear pin are assembled in the cylinder. Each cylinder assembly holds one control surfaces. Material selection is also an important factor in the design of FLM unit. Standard Pyro cartridges are assembled to the FLM unit for the functioning of the mechanism. As Pyro cartridge release high pressure gas the cylinder should withstand pressure load. Design of the cylinder is important consideration cylinder thickness and cylinder dimensions are more critical for mechanism. Design is made depend on the hole size of fin trailing edge the plunger pin is made by hole diameter of trailing edge of fin. Cylinder is designed based on the plunger and its stroke length and a hole is provided on the plunger in which shear pin is assembled

Design Criteria

The FLM unit objective is to hold the fin in locking position during the captive condition and free flight loads for 600ms after the fire command. The design requirements are as given below.

- Design of plunger to withstand fin loads.
- Design of cylinder to withstand high pressure gases generated by Pyro device.
- Shear Pin design for carriage loads and for releasing of plunger during free flight condition.

Design is made based on the considerations of plunger, fin load towards the plunger and Pyro cartridge pressure. Some of the calculations are done for the movement of piston, acceleration of piston and time for retraction. In the next chapter will able to find out the strength of the components by applying the pressure load in FEA Analysis.

Material Specifications

MDN 321

It is titanium stabilized austenitic stainless steel classed under heat and corrosion resistant steels. The alloy contains about 10% nickel and 10% chromium as main alloying elements and 0.8% maximum titanium as stabilizing element. The alloy corresponds to S 129 of British Standards, 12X18H10T of soviet standards. Z10CNT18 of French Standards. The alloy is specially developed for aeronautical application and in general for other industrial usage. The FLM unit objective is to hold the fin in locking position during the captive condition and free flight loads for 600ms after the fire command. The design requirements are as given below.

Physical Properties

- Grade: 321
- Density: 7.92 g/cm3 / 0.286 lb/in3
- Modulus of Elasticity in: 28X106 psi / 193 GPa
- Tension
- Melting Range: 1398–1446 C/2550–2635 F

Mechanical Properties

- Yield Strength, 0.2% Offset: 30,000 psi /241 MPa
- Ultimate Tensile Strength: 75,000 psi /515 MPa
- Percent Elongation in 2 in: 40
- Hardness, Max: 217
- Brinell: 95

Fin Load on the Piston

P1 x 2 = 71.5 x P2

P1 = 4000 N

P2 = 112 N

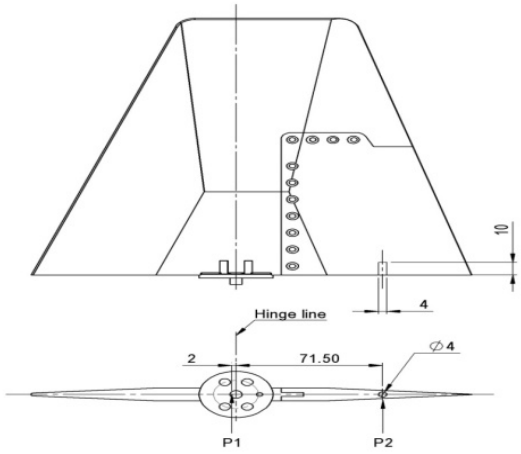

Figure 2: Geometric Details of FIN.

Force Required to Move the Piston

The resistance to the movement of piston due to Force required to shear the pin

External force due to fin

Frictional force

FEXT =External force due to fin load (N)

Ap = Area of the piston (mm2)

As = Shear area of the shear pin (mm2)

FS = Shear force of pin (N)

T =Shear stress (N/mm2)

μ = Co-efficient of friction

FR = Resisting force (N)

R = Norma reaction (N)

FR = FEXT + FS

= μR + As τ

= 0.1 X P2 + 3.14 X 300 (R = P2)

= 0.1 X 112 + 3.14 X 300

Considering a safe margin of 10% on resisting force (FR)

= 953 X 1.1

FR = 1048 N

Ap = $(\pi/4)d^2$

=3.14X50 = 157mm^2

Minimum pressure required in the chamber to move the plunger down is given b

$$P = \frac{F_R}{A_P} = \frac{1048}{157}$$

$$= \frac{1048}{157}$$

p = 6.6 MPa

Initial Pyro Cartridge Pressure

To operate the Fin locking mechanism PC025DQ is selected. The pressure developed inside the FLM is as given below:

Initial free volume (V1) = 8.04 cc

Free volume between piston and Pyro cartridge (VP) = 7.76 cc

Free volume emptied by explosive in Pyro cartridge (VE) = 0.28 cc

Mass of charge (m) = 250 mg

Empirical relation for calculation of Initial pressure (pmax) is given by

Pmax = 5.8√ (m/V_1)

Pmax = 5.8√(250/8.04)

Pmax = 32.34 MPa

Initial maximum pressure developed by combustion products pmax = 32.34 Mpa

Final Pressure after expansion

Combustion products will expand by poly-tropic law

Initial maximum pressure (p1 = pmax) = 32.34 MPa

Initial free volume (V1) = 8040 mm3

Final free volume (V2) = 9808 mm3

$P_2 = p_1(V1/V2)^{1.1}$

$p_2 = 32.34(8040/9808)^{1.1}$

p_2 = 26 MPa

FEA ANALYSIS OF FLM SYSTEM

The analysis of FLM model is done based on the pressure vessel consideration. As unit is completely closed and calculated pressure load is applied on the entire unit to verify stress and yield strength of material for individual components.

Figure 3: FEA Model of FLM.

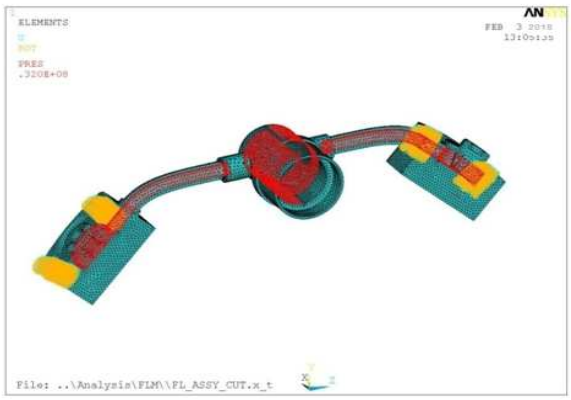

Figure 4: Pressure Load 32.5 Mpa.

The pressure load applied with boundary condition is shown in figure 3. The calculated pressure load of 32.5 Mpa is applied on the mechanism with closed condition and checking for maximum stress inside the FLM unit. The RED Zone in figure indicates the maximum stress up to which the unit can with stand.

ASSEMBLY AND WORKING OF FLM

Working of FLM Unit

A locking mechanism for moveable control fins are extending from the surface of a missile. The locking mechanism includes a pin extending thru the outer surface of the missile into an opening provided in the movable fin. A link is connected between each of the fins and a slide member inside the cylinder. The plunger is in top position when the pins are extended into the openings in each of the fins. Upon a command signal from a controller, preparatory to missile launch, a Pyro cartridge device release a high pressure gas towards distributor which distributes the gases through manifold towards cylinder and each of the plunger pins which are in cylinder exerts the pressure move the slide and extract the pins from the openings in the fins.

Assembly of FLM Unit

Each FLM units holds two fins in locked position. Two FLM units are used for holding of four fins in the missile Each FLM unit is held in position inside the nozzle cover by means of 8 No. of M4X0.7 fasteners and two M5X0.8 fasteners. Once the FLM units are positioned inside the nozzle cover the plungers will project out of the surface of the nozzle cover.

Table 1: List of Components in Flm Unit

Sl. No.	Nomenclature	Qty
01	Cylinder	02
02	Plunger	02
03	Shear pin	02
04	'O' ring-1	01
05	'O; ring-2	01
06	Bottom plate	01
07	Support plate	01
08	Distributor	01
09	Manifold	02
10	Connector	01
11	Pyro	01

Each of the plungers projected from the nozzle cover surface will enter into the hole provided inside the trailing edge of the fin and holds the fin in locked condition. Once the FLM is operated the plungers will be pushed down wards and the fins are unlocked.

CONCLUSIONS

In this research, a detailed study on Fin locking mechanism has been carried out to prove that this is one of the reliable mechanisms for missile applications. The calculated pressure load of 32.5 Mpa is applied on the mechanism with closed condition and checking for maximum stress inside the FLM unit. The unit will be pressurized using Hydro-static pressure facility in steps of 10bar up to 1.5 times of failure load on the shear pin and will be held for 60 seconds. In both the cases FLM unit have performed its intended function successfully. Pyro cartridge in FLM system plays a vital role and it provides high pressure gas to a greater extent towards the cylinders. For an applied input voltage, the Pyro Cartridge tends to be active and releases high pressure gas. On the other hand, various suggestions were made to improve the material of the components to increase the strength and to avoid failure of mechanism. Repeated ground tests are conducted on FLM System to check the performance of device. For a mechanism to be successful all the components which are involved are to be worked according to their intended function. Apart from the above discussions, Fin locking mechanism is used in most of the conventional missiles, rockets and bombs.

REFERENCES

1. *Md. Shahid Quamar, T. Manivannan (2001), Design, Analysis and Testing of Fin Locking Mechanisms for Fin Deployment System of an Aircraft External Store, ASMD.*
2. *Cackett, J. Basic principles and theory of pyrotechnics Marcel DekkersInc, 1985.*
3. *Mahadeshwar, A. M., Ghonge, A. S., & Chaudhari, K. A. Design, Development and Analysis of Differential Anti-Reverse Mechanism.*
4. *Developments in Pyrotechnics S. M. Danali, R. S. Palaiah, and K. C. Raha High Energy Materials Research Laboratory, Pune.*
5. *Missile Fin Locking Mechanism William W. Hsu, Glendale; Duncan D. Bragg, Simi Valley, both of CA (US)*
6. *Zaghloul, M. S. (2014). Design of Open Architecture Ship Alarm, Monitoring and Control System. International Journal of Research in Engineering & Technology, 2(1).*
7. *Mechanism for locking the missile Seung-gyo Jang, Hyo-nam Lee and Jong-yun Oh (2014).*

8. *ASTM A370–1996"standard test methods and definitions for mechanical Testing of steel products".*
9. *Ajani, A., & Olanrewaju, B. O. (2014). Avocado pear fruits and leaves aqueous extracts inhibit α-amylase, α-glucosidase and snp induced lipid peroxidation–an insight into mechanisms involve in management of type 2 diabetes. Int J Appl Nat Sci, 3, 21–34.*
10. *ASTM A604–1993"standard test method for macro etch testing of consumable Electrode re-melted steel bars and billets"*
11. *ASTM E4–01"Standard practice for force verification of testing Machines.*
12. *Anusha, S., Karpagam, G., & Bhuvaneswarri, E. (2014). Comparison of tuning methods of PID controller. International J. of Management, Information Technology and Engineering, 3, 1–8.*
13. *ASTM E220–86(R1996) "Standard test method for calibration of thermocouple by Comparison Techniques.*