

CHAPTER 15

PYROMECHANISMS

TABLE OF CONTENTS

15 PYROMECHANISMS	2
15.1 AWARENESS SUMMARY	2
15.1.1 Definition of a Pyromechanism	2
15.1.2 Background and History	2
15.1.3 Types and Uses	2
15.1.4 Advantages and Draw-backs of Using Pyromechanisms	6
15.1.5 Summary	6
15.2 TYPES OF PYROMECHANISMS	7
15.2.1 Detonating Devices	7
15.2.2 Deflagrating Devices	7
15.3 PYROMECHANICAL APPLICATIONS	8
15.3.1 Aircrew Egress	8
15.3.2 Missiles	9
15.3.3 Countermeasure Systems	11
15.3.4 Other Applications	12
15.4 DESIGN AND CONSTRUCTION	12
15.4.1 Design Overview	12
15.4.2 Electro-static Protection	15
15.4.3 Electro-magnetic Induction / Radio Frequency Protection	15
15.4.4 Detonating Devices	16
15.4.5 Deflagrating Devices	16
15.4.6 Design Considerations	23
15.5 CLASSIFICATION FOR TRANSPORTATION AND STORAGE	26
15.6 REFERENCES	28
15.7 BIBLIOGRAPHY	28

15 PYROMECHANISMS

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15.1 AWARENESS SUMMARY

15.1.1 Definition of a Pyromechanism

The term “pyromechanism” is used to describe a mechanical device that is capable of releasing energy stored in a chemical composition and harnessing this energy to perform useful mechanical work or to create particular mechanical effects. The chemical compositions used are generally of the energetic material type and energy is released from these by arranging for the material to undergo a combustion process. Pyromechanisms therefore require an input energy, usually in the form of an electric current or by means of mechanical percussion, in order to initiate the sequence. The energy outputs achieved can be orders of magnitude higher than the input energy and therefore these devices are very useful for performing functions where high thrust and energy are required from a low mass in small, confined spaces. Outputs tend to be in the form of mechanical motion, either linear or rotary and the vast majority of pyromechanisms contain all the high pressure gases produced during the combustion of the energetic material. The output is therefore a controlled mechanical movement or a directed effect to perform a particular function. A pyromechanism can therefore be thought of as a transducer, a device to convert energy from one form to another. The big advantage is the very large amplification between input and output energy.

15.1.2 Background and History

The concept of pyromechanisms has been largely developed since World War 2 where explosive bolts were successfully used in the German V1 and V2 weapon systems. This basic technology was further developed post-war by the US and Russian space programmes. The Apollo programme for instance used over 500 pyromechanical devices per mission for a variety of release and deployment tasks on the Saturn range of launch vehicles. Since that time the technology has seen a significant increase in the number of applications particularly in the weapon system and space domains. Other industries too have adopted pyromechanical devices and systems and these are now commonplace in safety systems on board road and rail vehicles and commercial airliners.

15.1.3 Types and Uses

Pyromechanism products are now well established in a number of fields and have found usage in many different defence related systems performing a variety of functions. Their ability to provide a high energy output from a small energy input makes them particularly useful where space is confined and remote operation is required.

Pyromechanisms can either be of the detonating (high explosive) type or a deflagrating type where a more controlled output is achieved. This distinction is used as a top level means of categorising pyromechanisms. In a detonating device the resultant shock is used to provide a directed fringing effect within a structure while in the deflagrating type the rapid release of gas is used to drive a mechanism.

Detonating pyromechanisms have found use where cutting or fringing effects are required. A good example is the explosive bolt shown in Figure 15-1 where a detonator is used to fracture a weakened portion of the bolt. The bolt can then be used to perform a release function where two structures held together by the bolt can be remotely separated. Another example is that of the military aircraft canopy fracture system to assist emergency aircrew egress. Essentially, this uses a detonator and a miniature detonating cord arranged in a pattern on the underside of the canopy. As part of the ejection sequence the detonator is fired and shatters the canopy.

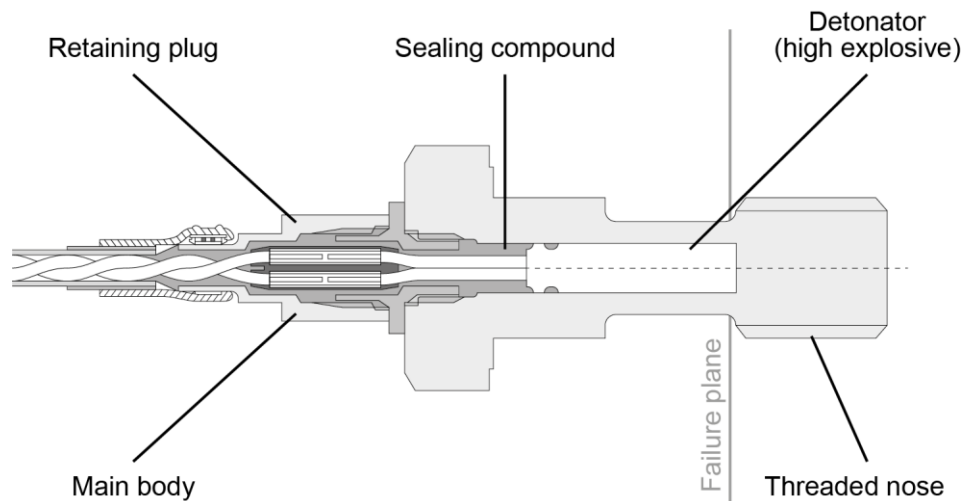


Figure 15-1 Cross-section of an exploding bolt (Courtesy of Chemring Energetics Ltd)

Deflagrating types are able to contain all the effects from burning the energetic material within the body of the pyromechanism and a whole range of mechanical functions have been derived from this such as piston protraction, piston retraction, cable cutting, separation and release. These functions are very useful in missile systems where power and space are limited and yet high force and energy outputs are required. Thus deflagrating pyromechanisms are used in missiles for launch motor separation, various detent applications, fin locking, wing unfolding and flight termination.

In nearly all examples of deflagrating pyromechanisms a confined propellant powder, usually black powder (see 4.2.1) or single base smokeless powder (see 12.2.2), is ignited and drives a piston. The forward movement can give mechanical thrust as in a protractor shown in Figure 15-2 or create the cutting action of a guillotine as shown in Figure 15-3.

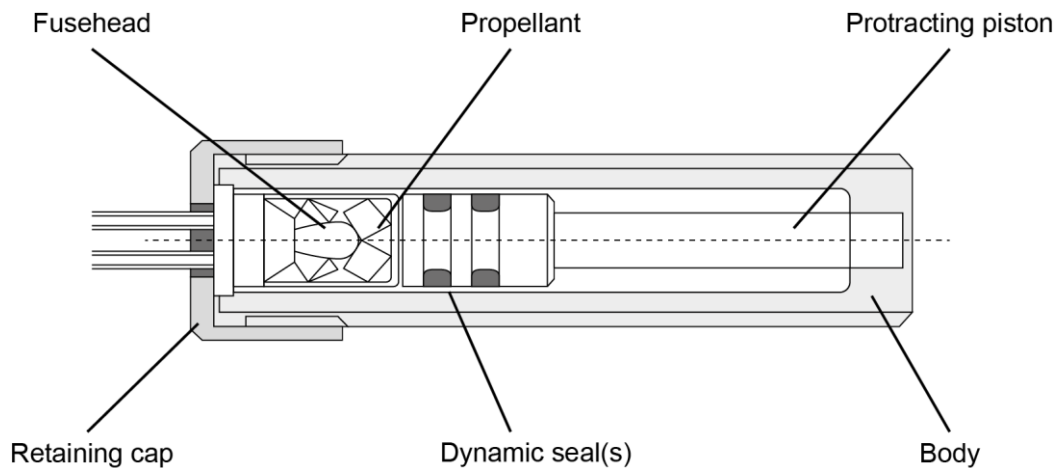


Figure 15-2 Cross-section of a typical protractor (Courtesy of Chemring Energetics Ltd)

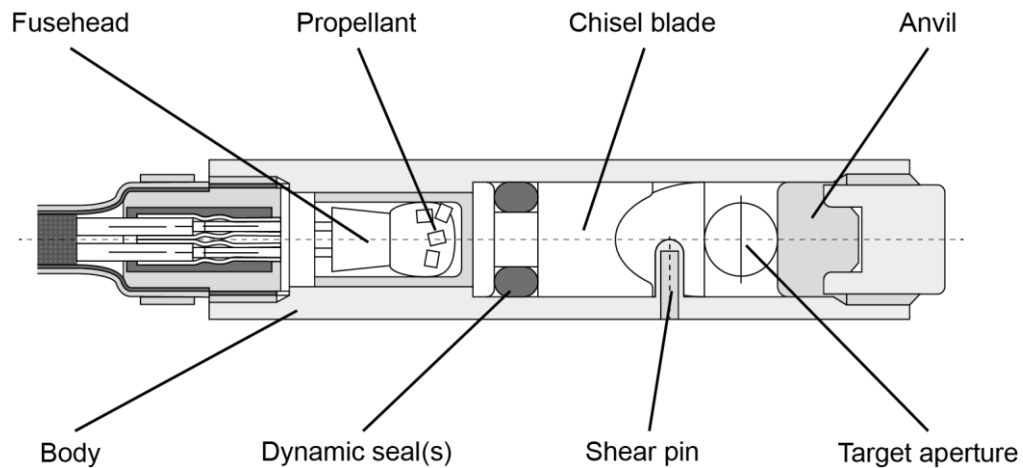


Figure 15-3 Cross-section of a pyromechanical cutter (Courtesy of Chemring Energetics Ltd)

A third major type of piston driven pyromechanism provides valves for controlling gas or liquid flow. They can be designed to either allow a flow to start or to stop. Figure 15-4 shows a valve where the flow line is closed and when fired the piston shears the barrier, which falls in to the trap below with the piston end closing off the hole produced in the pipe. In Figure 15-5 the flow line is open and when fired a blade cuts through the pipe forming a barrier to flow.

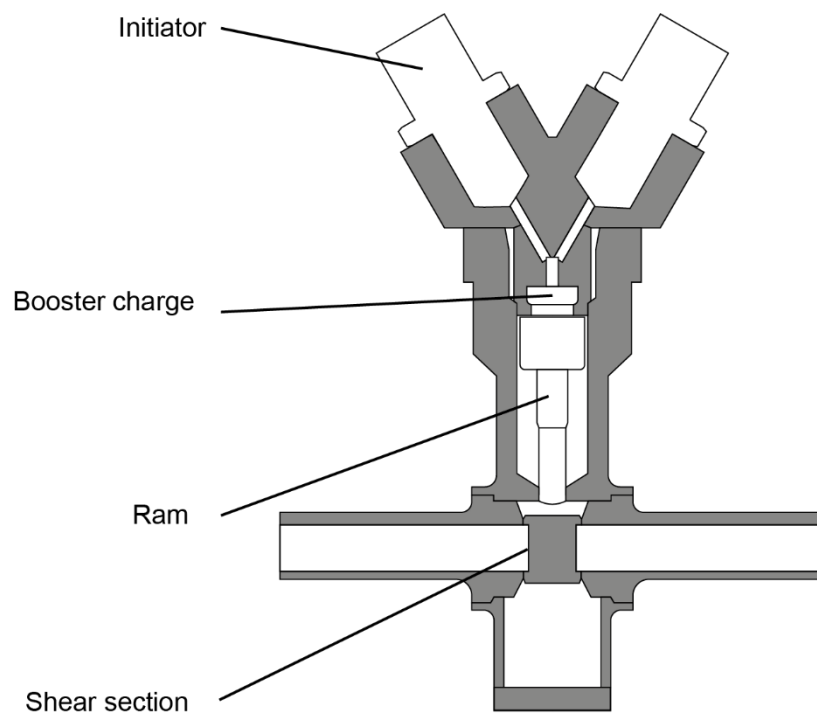


Figure 15-4 Cross-section of a normally closed valve

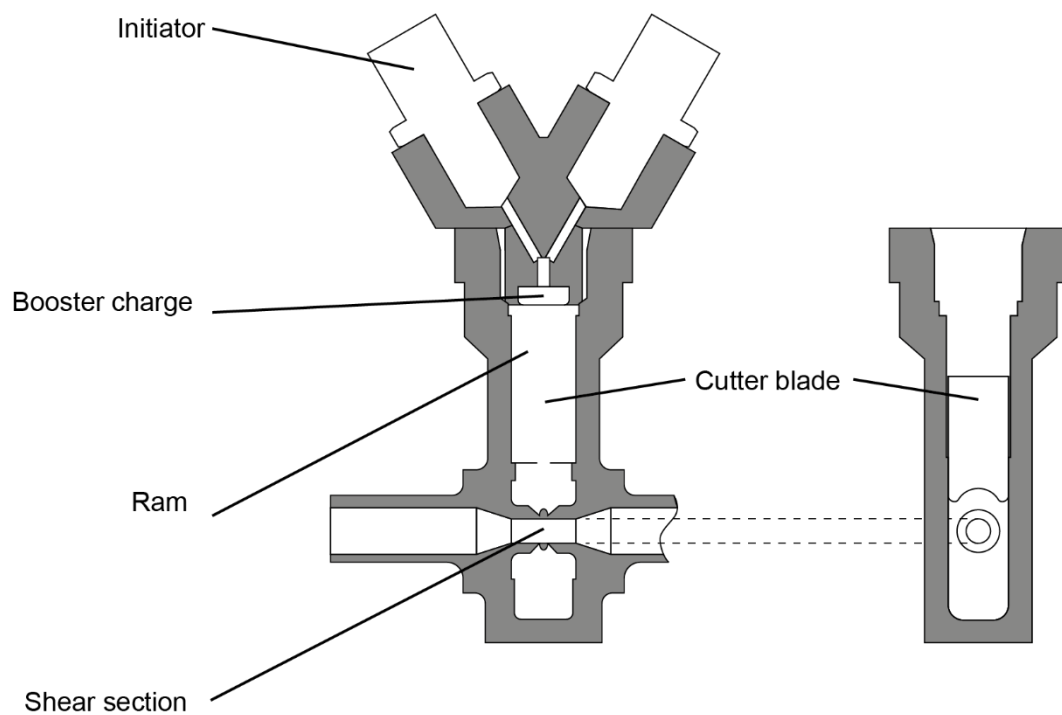


Figure 15-5 Cross-section of a normally open valve

15.1.4 Advantages and Drawbacks of Using Pyromechanisms

The very high energy density of the pyromechanism leads to relatively compact designs and this gives rise to a number of advantages over conventional (mechanical) stored energy systems. These advantages can be summarised as follows:

- i. Pyromechanisms incorporate all the necessary energy for the task
- ii. They are comparatively small and light and yet have considerable intrinsic energy and work potential
- iii. The designs permit remote operation either manually or automatically
- iv. The designs are robust and relatively unaffected by a range of environmental conditions
- v. They can be hermetically sealed and in the main all the explosive effects can be contained within the device (for deflagrating types)
- vi. Very little firing energy is required in return for the potentially large energy outputs from the system (this can be from electrical or mechanical input energy)
- vii. Response time can be, and usually is, very rapid, within a few milliseconds
- viii. Reliability of these devices is very high
- ix. Pyromechanisms require no maintenance throughout their service life.

There are also some draw-backs in the use of pyromechanisms. The principal disadvantage is that they all tend to be single shot devices. In this respect they can only be used once and actions are therefore irreversible. Due to the fact that they contain chemicals and elastomeric seals they have a finite life. This can depend on the material selected but lifespans offered by modern pyromechanisms are generally in line with other lifed items used within weapon systems. Other disadvantages can relate to the type of ignition system used and electrically initiated pyromechanisms in particular may require suitable protection from electromagnetic radiation and electro-static effects.

15.1.5 Summary

Pyromechanisms offer simple and elegant solutions to some complex problems. They are ideal where a high energy output is required from a low level energy source in a relatively compact space. They can perform a number of tasks operating as single shot prime movers, providing either mechanical motion or fringing effects. This makes them suitable for use in missiles, bombs, torpedoes, countermeasure systems and in aircrew egress systems to name but a few examples. Typical applications include release functions (e.g. bomb release), missile fin-locking and wing unfolding, launch motor separation, cable severance, flight termination, aircraft canopy break-up etc. This is just a small sample of possible uses for pyromechanisms and there are many other applications within space, automotive, aerospace and safety and security industries.

15.2 TYPES OF PYROMECHANISMS

Pyromechanisms may be divided into two broad categories; Detonating and Deflagrating devices.

15.2.1 Detonating Devices

This type of pyromechanism is initiated by a detonator and may or may not have a secondary charge. The main characteristic here is that the pyromechanism will produce some kind of disruptive effect on its surroundings but the effect is directed at performing a particular task. There may be some fragmentation or spatter associated with the functioning of the pyromechanism. This type of device is very likely to be included in UN Hazard Class 1 Explosives for transportation purposes because of the inherent hazards associated with it.

The pyromechanism uses the resultant shockwave to fracture surrounding materials. These can be metallic such as in explosive bolts where the detonative shock occurs along a weakened portion of the bolt to effect a separation. Other applications include devices to frange (disrupt/shatter) glass such as the covers on some ship launched missiles or acrylic screens such as in aircraft canopies. The essence of the design of a detonative pyromechanism is in the direction of the energy and the reduction of collateral damage. Effects should be kept to the local area and widespread, uncontrolled fragmentation would render the device unsuitable for the task in hand. The device does not use the shattering effect for the purposes of causing harm or random destruction.

Nearly all detonating pyromechanisms are initiated by a low voltage electrical signal that initiates a fusehead, which in turn ignites a primary explosive that burns to detonation (see 6.3.4.6).

15.2.2 Deflagrating Devices

These represent the more common type of pyromechanism and are probably preferred from an end user perspective due to the reduced hazards associated with this type of device. In the main, these pyromechanisms will contain all explosive effects and the only outputs are of a mechanical nature.

A deflagrating device can be considered in two parts. The first part contains the initiation system and the energetic material (generally a propelling charge). The second is a purely mechanical system which uses the energy produced from the energetic material to drive it. In this sense, pyromechanisms can either be fully integrated where the initiation system, energetic material and the mechanism are all housed in a single sealed unit, or can be split into their respective parts where the energetic part (the cartridge) is a separate item from the mechanical assembly. The latter comes under the description of either Cartridge Actuated Devices (CADS) or Propellant Actuated Devices (PADS). CADS/PADS tend to have a self-contained cartridge unit which can be screwed

into a pre-assembled mechanism. This type of system offers many advantages in that it enables the fitment of the energetic and therefore hazardous part immediately before use. It also offers the potential for modularity as different cartridge inputs and outputs can be selected and fitted in order to alter the characteristics of the mechanism. The concept of CADS/PADS leads to a range of gas generating squibs with different electrical firing characteristics and different gas yield in terms of the burn time and quantity of gas produced. This approach leads to thoughts of standardisation of cartridge fitment but the industry has yet to fully embrace this concept. NASA has probably come closest to achieving standardisation with the introduction of the NASA Standard Initiator (NSI). This is a qualified unit which can then be applied to a number of applications without further exhaustive testing. Associated mechanisms can be configured to receive one, two or even more cartridges which can assist overall system reliability. The downside here is that the overall pyromechanism tends to be rather bulky.

Integrated pyromechanisms on the other hand can be smaller for the same output and cheaper but offer reduced scope for alteration of input and output characteristics. There are, however, many examples of integrated pyromechanisms used within weapon systems and some of their mechanical functions are listed below:

- i. Puncturing containers (to release liquids or pressurised gas)
- ii. Pushing mechanical loads (e.g. opening valves)
- iii. Locking a device to prevent rotary or linear motion
- iv. Releasing a device to enable rotary or linear motion (using a retracting mechanism)
- v. Operating a switch
- vi. Cutting wires, cords, or small bolts

15.3 PYROMECHANICAL APPLICATIONS

Pyromechanisms have a wide range of uses in the defence industry and in particular can be found on aircraft, ships, missiles, bombs, torpedoes and countermeasure systems. Some example applications are given below:

15.3.1 Aircrew Egress

A number of pyromechanisms are used in fast jet aircrew egress systems where it is necessary to eject the crew through the canopy. Specifically designed ejection seats require a certain sequence of activities to be completed to enable safe ejection. Different types of pyromechanism are employed to achieve the required effects and these range from basic squibs (cartridges) for unlocking detents to complete release of the parachute once the seat is clear of the aircraft. To assist through-canopy ejection, a canopy break-up system is often employed. This takes the form of a miniature detonating cord (MDC) which is bonded on the underside of the aircraft canopy, which is constructed of either stretched or cast acrylic. The system is initiated by a detonator, often with mechanical initiation systems and this is activated by the first movement of the

seat. Transmission cord links the system to the MDC and conveys the detonation front to enable immediate break-up of the canopy. The MDC is arranged in a pattern which optimises the break-up ensuring no oversize fragments and a relatively free passage for the seat and its occupant. The explosive charge loading within the cord is sized to ensure sufficient cutting energy is imparted to the canopy and that the aircraft is not carrying excess energetic material in the vicinity of the aircrew. This is an example of a detonating pyromechanism where the system is designed to produce a shattering effect with minimal collateral damage as shown in Figure 15-6.



Figure 15-6 Miniature detonating cord (MDC) can be seen attached to the aircraft canopy (left) and completely fragments the canopy as part of the ejection sequence (right) (Courtesy of Chemring Energetics Ltd)

15.3.2 Missiles

Pyromechanical actuators, retention mechanisms, cutters, separation devices and weapon release cartridges all help to perform a range of critical “launch, fly, arm and operate” functions.

15.3.2.1 Weapon Release

Electrically initiated pyrotechnic cartridges (known as Cartridge, Ejector Release Units – CERU) are used to assist in providing a release and separation function from the aircraft. These cartridges produce a rapid supply of hot gas resulting from the burning of its propellant. The CERU uses the gas to drive pistons within the overall mechanism. The whole CERU plus the cartridge is considered to be a pyromechanism.

Missiles contained in a launch tubes may be “unlocked” as part of the launch sequence by electrically initiated retractors. The device shown in Figure 15-7 was designed for a shoulder launched anti-tank weapon. It has a retracting pin which operates a micro-switch for feedback once in the fully unlocked position.

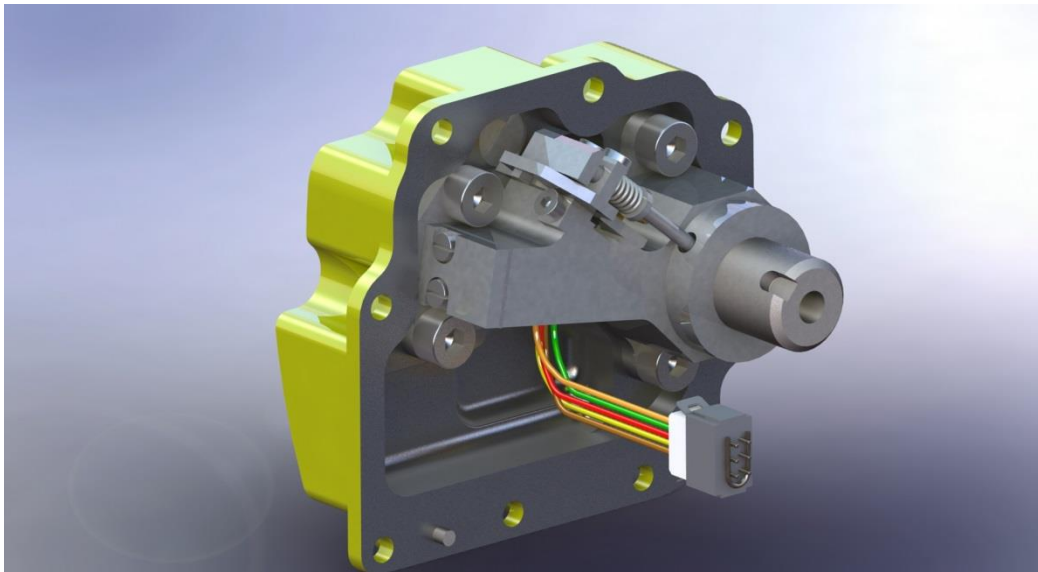


Figure 15-7 Retractable missile detent in shoulder-launched weapon (Courtesy of Chemring Energetics Ltd)

15.3.2.2 Fin Unlocking and Wing Unfolding

Integrated pyromechanisms are used to lock the control surfaces of a missile prior to deployment from an aircraft. On electrical command, the device unlocks the missile fins and allows autonomous control. Larger pyromechanisms can be used to unfold missile wings from the stowed position. Conventional pyromechanisms with fast burning propellants operate too quickly and may damage the wing on deployment. Therefore it is necessary to slow the operation down and sometimes fluid damping mechanisms are employed to give the wing a softer opening.

15.3.2.3 Booster Motor Release

Surface launched missiles that use solid booster motors to rapidly accelerate the missile during the launch phase require a means of releasing the motor after burn out. Pyromechanical release bolts or explosive bolts can be used to achieve this. Three or four units may be required to secure the motor and all can fire simultaneously to effect the release.

15.3.2.4 Missile Safe and Arm Units (SAU)

Although the latest complex weapons are tending towards the use of “in-line” warhead initiation, earlier systems used out-of-line SAU’s which required the use of pyromechanisms to enable alignment of the detonator with the booster. There are still a number of examples of this technology in service today. Here, pyromechanical protracting or retracting devices can be used to provide detents which when fired will initiate mechanical timing mechanisms.

15.3.2.5 Lug Retraction Devices

Upon actuation of a cartridge, a spring loaded rod extends to retract lugs into the missile body to reduce its radar cross section.

15.3.2.6 Valves

Pyromechanical valves are designed to be lightweight and reliable and these are critical to the liquid and gaseous fluid systems for complex missiles. Valves can be either designed in a normally open or normally closed configuration. Valves are typically associated with fuel flow and can be designed to isolate fuel during storage by sealing it within the fuel tank. Upon actuation the valve allows unrestricted fuel flow to the missile and in parallel, unrestricted flow of pressurised air back into the fuel tank. Conversely, a valve can be used to shut off the flow of fuel to act as a means of flight termination as described below.

15.3.2.7 Missile Flight Termination

There are a range of methods that can be used to terminate the flight of a missile and this may depend on the type of missile and its method of propulsion. Historically, shaped charge cutting cords have been utilised to completely sever the missile into two aerodynamically unstable parts. These tend to be rather complex requiring their own dedicated safety and arming units due to the presence of the detonators, booster and detonating cutting charge.

A simpler approach is employed on cruise missiles and the aim here is to terminate the fuel supply by either disrupting the fuel pump, cutting off the electrical power supply to it or to operate a valve to stop the fuel flow. Pyromechanical cutters or valves have been widely used to fulfil these tasks where their electrical means of initiation and compact and robust designs lend them to this application.

15.3.3 Countermeasure Systems

A number of applications have developed over the years using pyromechanisms in modern aircraft and ship countermeasure systems. These tend to be release type devices (bolts or nuts) or cable cutters. The unit shown in Figure 15-8 is from a towed electronic countermeasure used by fast military jets to defeat incoming missiles. It uses a dual ignition cable cutter for severance of the tow cable at the appropriate time. The dual ignition system enhances the reliability of the device to a very high level.

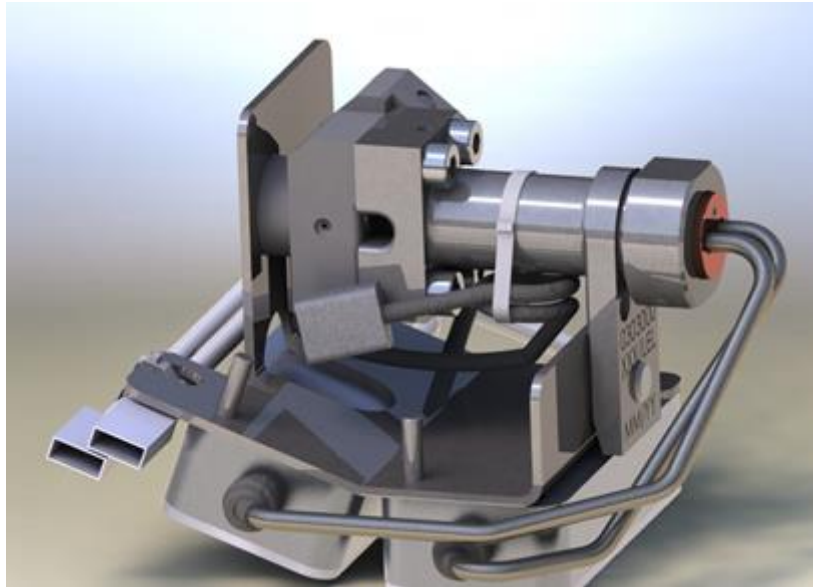


Figure 15-8 A pyromechanical cable cutter used on an aircraft decoy (Courtesy of Chemring Energetics Ltd)

The cable cutter in Figure 15-8 is protected by two electronic filters which are housed in the two boxes at the bottom of the image. These are connected to the cable cutter via the two sets of steel tubes. The design also includes a tellback feature to communicate that the cutter has operated and successfully cut the cable.

15.3.4 Other Applications

There are numerous other applications for pyromechanisms but one in particular worthy of mention is that used for gas bottle opening which has a specially configured piston. The piston penetrates the diaphragm in the top of the gas bottle and has a cut out section to allow the release of gas.

15.4 DESIGN AND CONSTRUCTION

There are many different types of pyromechanisms and it is not possible to cover all within a document of this nature. However, a selection of examples is considered below to illustrate the features of the common types and some aspects of the design of these are considered.

15.4.1 Design Overview

15.4.1.1 Overall architecture

Pyromechanisms, whether of the detonating or deflagrating type, have some common elements which assist in their overall environmental integrity, performance and reliability. First and foremost they have a means of initiation which can be either electrical or mechanical. There is usually a main charge, either propellant or high explosive material, a casing or housing that is usually

metallic, a means of sealing against environments incorporating glass to metal seals and the mechanism which is being driven.

15.4.1.2 Initiation

The vast majority of pyromechanisms are electrically initiated and use a range of low voltage type bridgewire igniters or detonators. There are a number of igniter products available with a variety of all-fire current levels and these can be incorporated into the pyromechanism. Selection of the igniter depends on a number of factors and one of the main drivers tends to be the availability of current from the firing circuit. Higher no-fire thresholds tend to be preferred for better protection from electro-magnetic effects. 1 Amp, 1 Watt, 5 Minute, No Fire igniters are effectively the industry standard and provide a high degree of protection to the pyromechanism and reduce the possibility of inadvertent initiation. These igniters require anything between 3 Amps and 5 Amps to be certain of firing. Lower threshold igniters can be used if there are limitations from the power supply but any device incorporating these is likely to require fully screened leads and possibly electronic filters to combat Radio Frequency/Electromagnetic Interference (RF/EMI) effects where induced currents can be created in the firing circuit. For most military applications, initiators should be characterised in accordance with STANAG 4560⁽¹⁾.

There are also mechanical means of initiating a pyromechanism and these use either percussion (see 6.2.2.4) or stab sensitive primers (see 6.2.2.3) or detonators. Percussion ignition systems tend to be more difficult to seal than electrically initiated pyromechanisms but they are not susceptible to RF/EMI. It is also more difficult to operate a percussion system remotely.

15.4.1.3 Energetic materials

Pyromechanisms make use of a range of energetic materials. The main charge is the driver behind the unit. Selection of the energetic material depends on the application and whether a disruptive or purely mechanical output is required.

Pyromechanisms intended for explosive cutting or break-up use a miniature detonating cord system incorporating PETN, HNS or RDX powders to achieve the desired effect. In aircraft canopy break-up systems, lead sheathed cord is currently used as this brings good flexibility and ability to bend around tight radii. Work is underway to identify suitable lead alternatives which will deliver similar handling and performance characteristics. This is primarily driven by EU REACH (see 1.3.2.4.6) regulations. Some disruptive pyromechanisms require only a detonator to perform the task and sometimes dished or conical ends are employed to enhance the performance using a Shaped Charge effect (see 8.1.3).

Deflagrating pyromechanisms usually require a fast burning charge. Single base NC small arms propellants (see 12.2.2) lend themselves well to this application. These materials are easy to initiate, are available in volume production and burn at the required rate to enable the pyromechanism to perform its duty. They are very efficient at producing hot gas which is used to

drive the mechanism. The NC incorporates a stabiliser (see 12.2.4.1) which assists in maintaining the propellant in a safe state and prolongs the life of such material. Single base NC is very tolerant of a wide range of temperatures and will meet the majority of weapon system requirements.

Black powder (gunpowder) is also very common as a main charge within pyromechanisms. Again this burns very rapidly (in the loose filled state), although it is not as efficient as NC for producing gas and it yields a lot of solids in the products of combustion. Black powder is a relatively stable material and is useful for pyromechanisms requiring good longevity.

15.4.1.4 Housings

Unless specifically designed to provide a disruptive effect, a key requirement for a pyromechanism is to contain its explosive event and channel the energy into a mechanical movement. This places great importance on the structure and in many cases requires the structure to cope with very high pressure levels. It is not uncommon for a pyromechanism to generate an internal pressure in the range of 200 – 500 MPa (2000 – 5000 bar). Material selection is therefore critical. The deciding factors may be a choice between size and mass. Very high strength steels can be employed to provide the thinnest wall section to cope with a particular pressure level. High strength stainless steels such as precipitation hardening steels (to BS 2S143/145) are good for their combined strength and corrosion resistance. Smaller, lower power pyromechanism housings can be manufactured in free machining brass and aluminium. These materials are good at containing lower pressure events and are cheaper to produce than their high strength steel counterparts. All materials used in contact with the energetic material must be tested for compatibility (see 20.10.3.1).

15.4.1.5 Sealing

For electrically initiated pyromechanisms, it is necessary to convey the electrical firing pulse to the igniter which is normally housed inside the pyromechanism body. In order to maintain a good hermetic seal, the igniters are often mounted on glass to metal seals (GTMS) and this allows the current to be conducted through the seal via pins which pass through the glass beads. These GTMS are capable of withstanding high pressure for short periods and have been proven over many years use within pyromechanisms.

Percussion initiated pyromechanisms are much more difficult to seal. Most of the conventional percussion primers (link to 6.2.2.4) are not capable of holding high pressure gas post function and therefore some means of back-up is required. This can result in elaborate striker mechanisms which use elastomeric O ring seals on the striker parts. The issue here is that the O rings absorb significant amounts of striker energy and compensation needs to be made in the energy source.

Pistons on protracting or retracting mechanisms use elastomeric O rings to prevent gas escape and keep all explosive effects within the housing. Ethylene propylene diene monomer (EPDM) rubber is a common material for the O ring

as it is compatible (see 20.10.3.1) with most energetic materials, tolerates high temperature for short durations and offers good longevity.

15.4.2 Electro-static Protection

Electrically initiated pyromechanisms are prone to inadvertent actuation through electro-static discharge (ESD). Build-up of static electricity can cause problems unless the pyromechanism has suitable protection designed in. Any discharge taking place within the device around the energetic material chamber is likely to cause ignition. A common failure mode is where discharge takes place between the electrical pins and the metallic body of the device. The design of the pyromechanism needs to take account of this and many pyromechanisms now offer some insulation between the internal walls of the device and the igniter using a suitably compatible plastic with high a di-electric strength.

A number of tests have been developed over the years to simulate various electro-static environments and these tests are used to determine the adequacy of the pyromechanism to cope with electro-static discharge. The most common test involves charging a 500 pF capacitor to 25 kV and then discharging this through either the pins to case or pin to pin with a 5000 Ohm or 500 Ohm resistor connected in series. This represents a worst case human discharge and is therefore appropriate for ensuring the device is safe to handle. Such tests are standardised and defined in common EED standards such as MIL-DTL-23659F⁽²⁾ and STANAG 4560⁽³⁾.

Other techniques to combat ESD include appropriately designed air gaps which encourage the discharge to take place outside of the energetic chamber. This technique works well but relies on there being no foreign matter entering the air gap.

15.4.3 Radio Frequency/Electro-magnetic Induction Protection

Another common issue with electrically initiated pyromechanisms relates to their behaviour in strong electromagnetic fields and in close proximity to radio transmitters. Such fields can generate sufficient electrical current in the firing circuits and if this is above the no-fire level of the igniter, the pyromechanism can fire inadvertently. As with other explosive systems there are means to combat this by including certain features in the design. Perhaps the most obvious is the selection of a high threshold igniter. The 1 Amp, 1 Watt, 5 Minute, No Fire types are particularly good at coping with RF/EMI environments but they require a reasonable level of firing energy from the circuit and this may not always be possible. Twisted pairs help reduce the chance of inductive pick-up but are not adequate on their own. Screening of the electrical leads is effective provided all joints and terminations maintain the screen through 360°. It may also be necessary to ensure the pyromechanism sits in a complete Faraday cage. Electronic Filters are also widely used in the design of the firing circuits. These tend to be of the capacitive low pass type which filters out unwanted high frequency signals. EMI suppression filters are also common and their fairly small and compact design does not add too greatly to the overall size and mass

of the pyromechanism. These filters can also assist with the electro-static discharge as most have built-in bleed resistors to earth.

15.4.4 Detonating Devices

15.4.4.1 Explosive bolts

The use of the explosive bolt has a long history, principally to facilitate the remote and rapid release or separation of one object from another. It relies on the principle of brisance to cause structural failure; brisance being defined as “the ability of an explosive to shatter the medium which contains it”. In this case, the explosion involves a detonation shock wave, which leads to failure along a predefined plane.

The principal advantage of the explosive bolt is its simplicity having no moving parts and as such it is a relatively low cost solution as a separation mechanism; however, there are several major disadvantages:-

- It utilises high explosive material
- On functioning, it releases hot gasses and combustion products at high pressure, together with fragmentation of the metal body.
- Its detonation may impart a significant shock to the structure to which it is attached.

In many cases, these will be highly undesirable characteristics.

15.4.5 Deflagrating Devices

15.4.5.1 Protractors

The protractor represents the simplest form of pyromechanism in use today. As its name suggests it is designed to protract with a pushing motion in relation to its body. When initiated, the rapid gas expansion resulting from the burning propellant forces a sealed piston forward with a calculated amount of energy. This energy can then be used to do work outside the device itself. In Figure 15-9 the igniter within the protractor can be seen to be protected by a plastic insulation sleeve. This prevents any possibility of electrical discharge between the walls of the device and the igniter pins and thus renders it safe from inadvertent firing to electro-static effects.

The whole structure has been designed to contain all the effects of the “explosive” event and therefore all wall thicknesses have been sized to contain the very high transient pressures. Equally, the base of the protractor is capable of arresting the piston which travels at high velocity until it impacts on the base at the end of its stroke. The piston is prevented from moving by a shear device. The illustration above shows a “septum” feature at the base of the unit which holds the piston in place until, on initiation, the internal gas pressure builds up to a point where the resultant force on the piston breaks the septum. Shear devices can be used to tune the protractor and this can alter its characteristics.

The design of the protractor includes an electrical igniter which is mounted on a glass to metal seal. The latter helps retain all the flame and gaseous effects. For small protractors the only explosive present may be the fusehead.

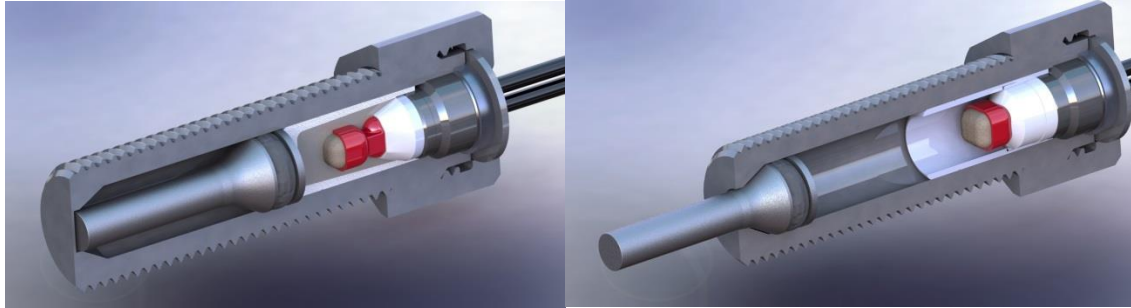


Figure 15-9 Protractor in the unfired (left) and fired (right) positions (Courtesy of Chemring Energetics Ltd)

The performance of protractors that use fast burning explosive powders and propellants have a characteristic thrust profile. The majority of burning takes place before the piston starts to move and therefore the highest thrust occurs at this point. Once the shear element has failed, the piston then accelerates rapidly driven by the expanding gas until it arrests on the base of the unit. Placing axial loads on the piston will change the overall characteristic as the energy in the gas is given up to moving the load. The lowest thrust will always occur at the end of the stroke.

It is very easy to measure the energy and thrust output from a protractor. Energy measurement systems utilise a known mass which is propelled vertically. The height the mass achieves is recorded and this is used to compute the energy output through a simple “mass x gravitational constant x height” calculation. Alternative energy measurement methods use a pendulum approach where a mass suspended on a pendulum arm undergoes an angular displacement when receiving energy from the protractor. The angular displacement is then converted to an energy value through a simple algorithm. Thrust can be measured by operating the protractor with a suitable load cell in the system.

There are many protractors on the market with various characteristics and these products tend to be defined by their stroke length, energy or thrust output and electrical firing characteristics. In some sectors there has been some standardisation regarding installation features and it therefore becomes possible to interchange protractors from different manufacturers.

15.4.5.2 Retractors

The retractor is designed to have a pulling motion in relation to its body. It achieves this based on gas pressure acting on the differential area between the piston shank and the piston head. Each part of the piston is sealed by an appropriate O ring. There are various designs of retractor in existence but the common types either have integrated energetics to maintain the slender profile of the device or they have a side-entry gas cartridge.

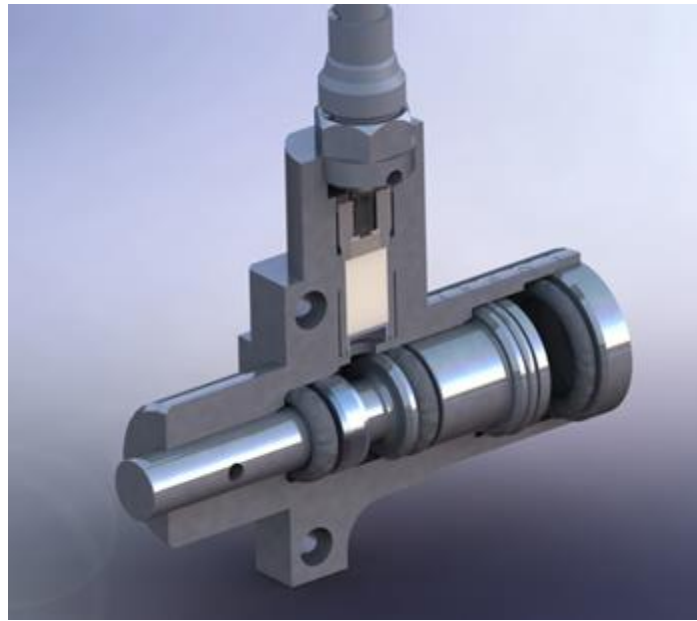


Figure 15-10 Retracting device with side entry gas cartridge (Courtesy of Chemring Energetics Ltd)

On firing, the gas pressure is directed to the void between the two O ring seals by means of ports, thereby causing the piston to retract inside the body. It can be seen from Figure 15-10 that the design of the retractor is necessarily more involved, generally resulting in a larger space envelope and higher cost than that of an equivalent protractor. For these reasons, its use is less frequent than the protractor; however, in some applications it does provide the most appropriate, reliable and cost effective solution to the needs of the designer. As with the protractor, the retractor has built in ESD protection.

Assessment of retractor performance is usually made by applying side loads to the piston and then operating it to determine whether the device is capable of fully retracting. Excess loads are applied to prove the margin in performance. The bulk of retractor applications involve operating against a side load so this is a representative means of testing. As with the protractor, the highest thrust takes place at the start of the stroke and decays once the gas expands and cools. Again, it is common for the piston within the retractor to be held in place by a shear device (commonly a shear pin). This can be used to tune the performance of the retractor during the design phase.

15.4.5.3 Cable cutters

In essence, the pyromechanical cutter is a protractor with a blade embodied in the piston nose, an end-of-stroke anvil to arrest it, and an aperture between, to locate the target.

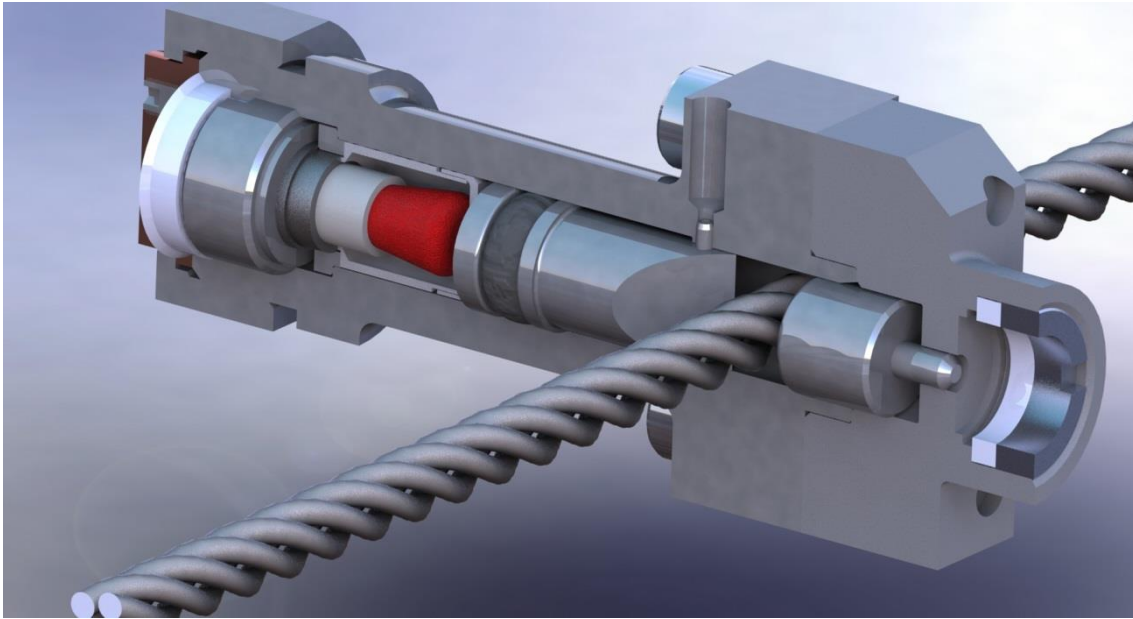


Figure 15-11 Pyromechanical cutter with target cable (Courtesy of Chemring Energetics Ltd)

The simplest form of cutter, illustrated in Figure 15-11, for cutting typically plain wire, cable or rope, employs a chisel blade, with a through-hole (target aperture) through which the target is threaded, normal to it and adjacent to the anvil. The cutting method here is similar to that of an axe where the target fails through a combination of shear and tensile failure; however, depending on size and geometric arrangement, the alternative of a circular blade which acts more like a pastry cutter may be used.

Cutter mechanisms also can be designed with side openings or removable anvils; thus allowing the cutter to be brought to the target (in situ). This eliminates the need for the cutter to be permanently fixed, and hence the need for “threading” the target. As such they can be used to cut many different types of targets from very thin cords and wires, to solid tool steel bars.

Figure 15-12 shows a large pyromechanical cutter which is capable of severing a 100 mm diameter steel armoured cable. The cable aperture is on the right hand side of the view. As can be imagined a high propellant load is required to cut the target and this gives rise to very high pressure inside the device. This has resulted in a finished product of 1.2 meters in length and a mass in excess of 150 kg due to the high strength casing. This particular cutter has spent several years on the sea bed and although there is high degree of surface corrosion, the components of the cutter remain pristine and fully operational. This demonstrates the potential robustness of a properly designed pyromechanism with adequate sealing.



Figure 15-12 Pyromechanical cable cutter designed for a deep sea environment (Courtesy of Chemring Energetics Ltd)

15.4.5.4 Release Bolts

The release bolt is another derivative of the protractor; in this case however, doing all the work inside the device with a very short stroke of the piston.

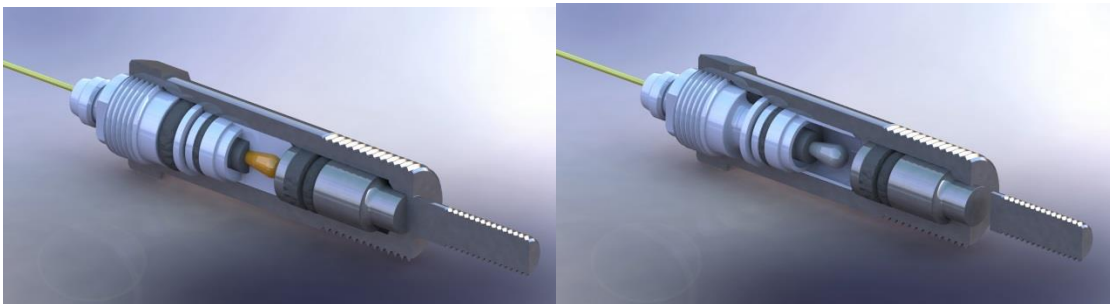


Figure 15-13 Release bolt in the unfired (left) and fired (right) positions (Courtesy of Chemring Energetics Ltd)

As can be seen in Figure 15-13, the piston (at rest) is mounted in a stall condition relative to the bolt shank, so that during the initial stage of gas generation the piston is restrained from moving forward. When the design pressure is reached, the piston is thrust forward a short distance to cause shear failure of the shank at the predefined circumferential shear plane; thereby allowing the threaded nose of the bolt to break away, whilst retaining the piston in the main body of the bolt.

Immediately, the advantages of this device over the explosive bolt are apparent:-

- It does not utilise high explosive material
- Upon functioning, the device separates into two parts only, with no fragmentation
- After functioning, it contains all products of combustion
- There is no detonation shock wave

Release nuts are also commonly used (in lieu of the release bolts). Both release bolts and release nuts can be designed with recoil-less features to reduce further the effects on the surrounding structure.

15.4.5.5 Pyromechanical valves

The pyromechanical valve comes into its own for handling fluids which require highly reliable sealing and isolation for long storage periods, where traditional valve techniques are inappropriate or inadequate. It is particularly useful when handling volatile, corrosive or hazardous fluids, which would quickly destroy conventional synthetic sealing materials. Typical applications would be fuel lines for rockets or torpedoes, where any leakage and/or evaporation cannot be tolerated.

Its principle of operation is not dissimilar to that of the release bolt, where an advancing piston is used to cause failure at a predetermined shear plane (two in this case) as shown in Figure 15-14. In this application however, the piston has a much longer stroke, so that after shearing the blind ends, it continues to end of stroke, where it presents an aperture to the flow-line thus permitting fluid flow.

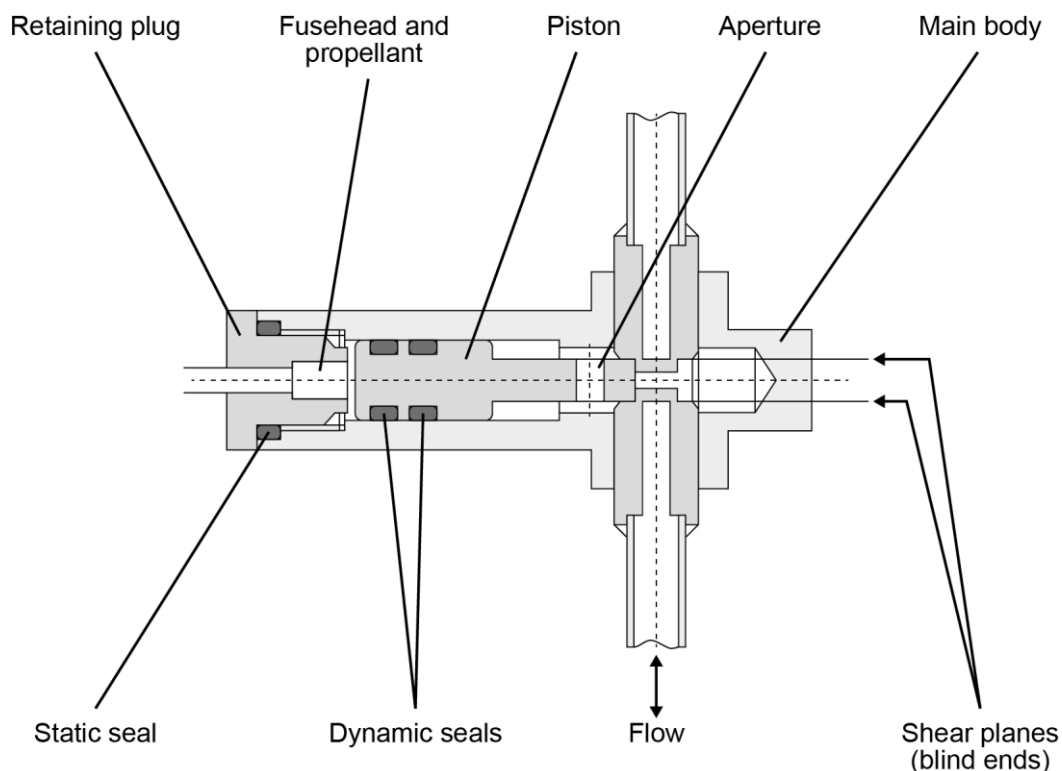


Figure 15-14 A typical pyromechanical valve layout (Courtesy of Chemring Energetics Ltd)

The valves can be configured in different ways to provide either normally open (NO) or normally closed (NC) options. In some instances it is possible to have

dual function valves that change state from closed to open and then closed again. These, however, result in fairly complex, bulky and expensive valves.

15.4.5.6 Damped pyromechanisms

The majority of pyromechanisms that use a fast burning propellant tend to have a very fast function time. As such, the event can be over within 10 or 20 milliseconds. The speed at which they operate can impart much shock into the surrounding structure and such fast operation may not be suitable for some applications. To combat this, there are techniques to slow down the operation cycle. One such technique employs a damping fluid.

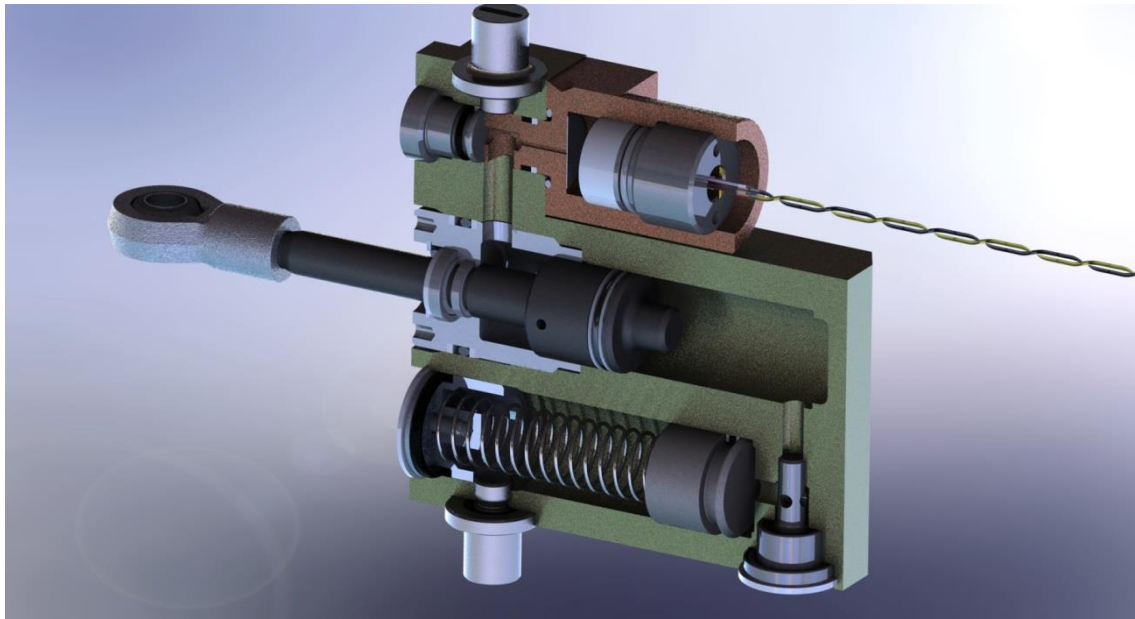


Figure 15-15 A damped pyromechanical retracting device (Courtesy of Chemring Energetics Ltd)

Figure 15-15 shows the layout of a damped pyromechanical retracting device. This particular unit has a gas generating cartridge at the top of the picture which contains a single base, rapid burning NC propellant. On activation, the high pressure gas is directed to the main cylinder via a port and this acts on a sealed piston. On the other side of the piston is a damping fluid which is held in situ behind a diaphragm that covers a small orifice. When the pressure imparted to the fluid reaches a certain level, the diaphragm is ruptured and the fluid flows through the orifice and into a second chamber. The orifice controls the mass flow rate of the fluid and this provides a damping action on the piston. The fluid then collects in the second chamber and drives the second piston down the bore of the empty chamber. This action provides a more controlled displacement vs. time profile and results in operating time in the hundreds of milliseconds rather than tens of milliseconds. The pulling motion of the retractor is therefore suitable for applications such as cruise missile wing unfolding where wing inertial loads may cause problems under a fast acting actuator. Selection of the damping fluid is crucial in a damped pyromechanism. It is important the material is stable over a wide temperature range.

15.4.6 Design Considerations

15.4.6.1 Performance

As pyromechanisms generate considerable energy in relation to their size, it is important when developing a new device, that apart from the obvious need to ensure it meets all aspects of the operational requirements, there is not too much unwanted energy produced that might put unnecessary stress on adjacent components. It is therefore important to fully understand the relevant parts of the system which interface with the pyromechanism. The external loads placed on a pyromechanism can considerably influence its performance and the design needs to be able to cope with the extreme pressures of a stall condition.

Modern day pyromechanical design makes good use of computational techniques and this can be underpinned with real test firing data. To enable the most accurate performance simulation, the particular propellant that is to be used in the pyromechanism must be characterised, that is to say that its burning rate/pressure/time performance must be fully understood and expressed mathematically. The resultant model is then improved and refined with the feedback of test firing results and the comparison of the actuals with the predictions. This approach reduces the amount of iterative testing required during development and results in a more precisely engineered product with a shorter and more effective non-recurring element of the development programme, prior to commitment to manufacture, and has clear benefits in terms of cost and programme time scale.

Peak pressures developed within a deflagrating pyromechanism typically lie between 200 and 500 MPa (2000 – 5000 bar). In normal operation the peak pressure is only a transient, nevertheless it should not be forgotten that to qualify as a non-explosive device the pyromechanism needs to contain the developed pressure for an extended period of time.

Response times have been stated as being short; generally in the order of 10 - 20 milliseconds from the time of application of the firing pulse to the mechanical action being complete. By way of illustration, Figure 15-16 below shows the recorded pressure/time curve from the actual firing of a large pyromechanical cutter where the vertical axis shows the internally generated pressure (bar), and the horizontal axis the elapsed time (milliseconds).

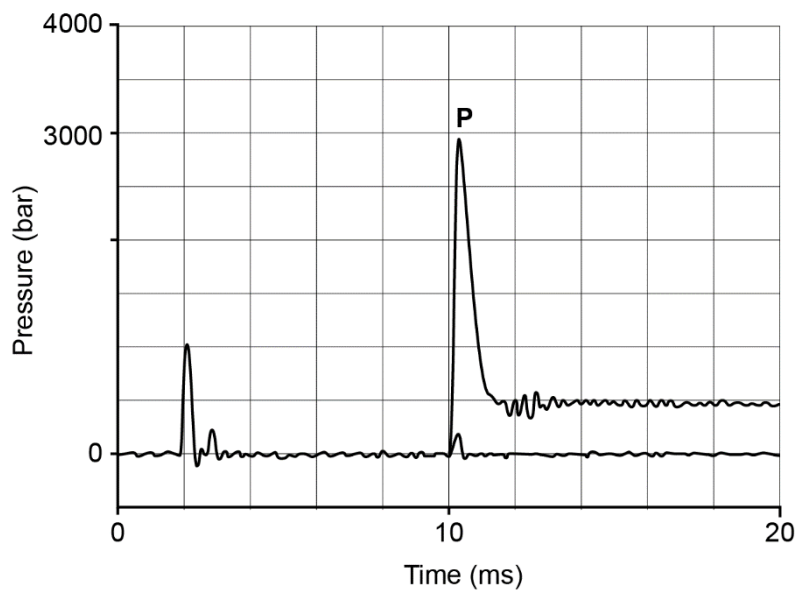


Figure 15-16 Typical pressure v time curve of a large pyromechanical cutter

The peak value “P” at nominally 10.5 ms indicates the maximum internal pressure inside the device and it can be seen that there is a delay of only 8 ms from the firing pulse (at 2 ms) to the start of pressure rise. This is the time it takes for the electrical energy applied to the igniter to cause the pyrotechnic composition to inflame and start the combustion of the propellant. Once the propellant has started to burn, the pressure/burning rate escalation effect (see 7.2.3.2) produces a near vertical pressure rise up to 300 MPa (3000 bar). Allowing for the accuracy of the recording instrumentation, the pressure rise clearly takes less than a millisecond. Peak pressure soon decays once the piston/cutter blade moves, increasing the internal volume, and the heat, generated during combustion, is dissipated through the metalwork of the body. Again, this occurs in a timeframe of less than 10 ms.

The velocity of the blade reaches a peak of approximately 90 m s^{-1} , and the whole cutting operation takes place in 10 ms. This can be put into perspective when it is realised that a blink of the human eye takes approximately 45 ms.

15.4.6.2 Environments

As most pyromechanisms are of sealed construction, they will not generally be adversely affected by their environment, whether underwater, in air, or in outer space. They are of rugged construction and generally unaffected by the extremes of shock and vibration levels to which military weapon systems are typically subjected. However, before embarking on the design of a pyromechanism, the environment in which it will perform must be fully understood, particularly with respect to the temperature in service. Pyromechanisms generally cope well with a temperature range of -54°C to $+85^\circ\text{C}$ provided there are only short duration excursions to the higher limit.

Very high levels of shock can cause problems to a pyromechanism unless it has appropriate features built into the design and the general rule here is to make sure that none of the internal components are unsupported.

As stated earlier, electromagnetic environments will have an effect on the pyromechanism and it is important to establish the details of this as it may require special measures to be taken with the design of the pyromechanism such as provision of filter boxes and screened twisted pairs to protect the circuits.

15.4.6.3 Reliability

As a “single shot” device it is very important, particularly in safety related applications, that the pyromechanism operates when it is required to do so and does not inadvertently operate when in stand-by mode. The reliability of pyromechanisms is therefore crucial. There are a number of methods of assessing the reliability of a pyromechanism and the most common method is by testing although this is not the most cost effective. Testing a large quantity of pyromechanisms will enable the statistical assessment of reliability. For example, if 298 one shot devices are tested without failure this equates to a reliability of 0.99 with 95 % confidence.

Budget and time constraints often preclude testing as a means of establishing reliability, particularly where very high levels of reliability need to be proven. Other methods that can be used are by “parts count” where published failure rates are assigned to the components of the pyromechanism. A base rate failure is then computed and this may be modified with environmental factors to take account of the lifecycle profile of the device.

Pyromechanisms have a good track record for reliability and it is not uncommon to see reliability levels of 0.998 or better depending on the type of pyromechanism, the life and the environment.

15.4.6.4 Life

The main enemy of modern explosives from the point of view of longevity is temperature. As all explosives decompose at a rate directly related to the temperature to which they are exposed, the life of any pyromechanism becomes a function of the type of explosive material that it contains and its environment, in terms of maximum level of, and fluctuations in, temperature. Consequently a pyromechanism which is subjected to high temperatures for prolonged periods will not exhibit as long a life as it would if kept reasonably cool, say at about 20 °C.

As a precursor to a comprehensive in-service real time surveillance programme it is possible to calculate the expected life of pyromechanisms containing single base propellants by maintaining them at an elevated temperature for a given length of time and then measuring the performance in a standard rig. This performance is then compared with the pre-trial performance to provide a measure of any deterioration.

The relationship between the temperature of storage and the total life can be estimated by application of equation ((15-1).

$$P_1 = P_2 \cdot A^{(T_2 - T_1) / 10} \quad (15-1)$$

Equation (15-1) with an Arrhenius factor A, which is specific to each explosive and usually in the range of 2 to 3, shows that equal degradation is produced in an explosive stored either for a period P_1 at temperature T_1 , or for a period P_2 at a temperature T_2 .

Although the above equation has limitations, it is valuable for initial estimates. The accuracy of an accelerated ageing programme starts to become compromised if prediction periods (P_1) greater than 10 years are used. Under these circumstances a combination of real time storage and accelerated ageing may be used to good effect. To make the best use of this technique a 'stockpile to target' sequence for the weapon system is required which predicts what fraction of its total life it will spend in any given environmental condition.

Many pyromechanisms are capable of achieving a life of ten or more years depending on the environments and the pyrotechnic materials selected. Unless refurbishment is an option for some of the larger pyromechanisms (see below), time expired pyromechanisms must be disposed of and replaced.

15.4.6.5 Safety

Safety of pyromechanisms is paramount. The majority of pyromechanisms are designed to contain very high pressure events. It is therefore vital that adequate safety factors are provided in the design to ensure sound integrity of the device. All hazards associated with the pyromechanism must be fully understood and this can be achieved by conducting an appropriate hazard analysis. Construction of a product safety case to accompany each design is now mandatory and in general these are compiled in accordance with Def Stan 00-56⁽⁴⁾.

15.4.6.6 Refurbishment

Pyromechanisms, are by nature, 'one shot' devices; however, under the right circumstances, refurbishment can be an option. The factor that controls this is mainly the cost of refurbishment compared with the cost of a new item. Even if a device is recoverable after use, its refurbishment will not necessarily be economically viable unless the device is sufficiently large enough to justify it. If refurbishment is a requirement, then the designer must be made aware of this at the very earliest stage in the design process, as it is necessary to incorporate this feature into the baseline product; retrofitting not being a practical option.

15.5 CLASSIFICATION FOR TRANSPORTATION AND STORAGE

It may seem a contradiction to even consider that an item containing explosive material could be legally classified as a "non-explosive" article. However

provided that specific criteria are fully satisfied, it is certainly true as far as the UK authorities are concerned.

The criteria are:-

- The total net explosive content must not exceed 100 mg
- There must be no emission of hot gas or explosive effects outside the device during or after functioning
- Initiation must be electrical, not mechanical
- If a cutter: the target aperture must be no greater than 5 mm
- Any external mechanical motion must not exceed 20 mm

Classification as “non-explosive”, and therefore exemption from the terms of ER 2014⁽⁵⁾ and associated legislation on the transport of explosives⁽⁶⁾, simplifies and makes cheaper the storage, transport and handling of the devices for both supplier and user.

Any newly developed pyromechanism must be tested during its development phase to demonstrate the maintenance of its structural integrity at the extremes of its performance envelope. It will be evaluated in a representative stall condition, where the piston is prevented from moving when fired; thereby subjecting it to the maximum possible internal pressure to confirm that it will not rupture or explode under this extreme condition. Additionally the device is tested with no load on the piston, so as to achieve maximum velocity by the end of stroke, at which point it must be arrested within the structure, and demonstrate that it will not be ejected from the mechanism.

There are a number of protractors, retractors and cable cutters that have achieved an exemption from Dangerous Goods Class 1 Explosives. However, any detonating (disruptive) pyromechanical system is likely to carry an explosive hazard classification of 1.4S at best.

15.6 REFERENCES

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- [4] Defence Standard 00-56 Issue 04, Part 1, *Safety Management Requirements for Defence Systems*, UK MoD, 2007
- [5] The Explosives Regulations 2014
- [6] The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 ("CDG 2009"),

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