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(54) Gun-launched rocket

Von einem Rohr verschossene Rakete

Roquette lancée par canon

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Description

[0001] The present invention is related to a case and closure design for a rocket motor, in particular for a gun-launched rocket. More particularly, the present invention relates to an insensitive munitions system employing one or more passages and an internal compression chamber system which collectively accommodates gas pressures inherent in gun-launched rocket systems in a manner allowing for a thinner rocket motor case cylinder and increased propellant volume beyond what prior art permits. These systems may be used in combination or separately.

[0002] Many launchable projectiles or rockets are comprised of a forward end, including guidance and munitions, and an aft end rocket motor. These two elements can be formed together, with a common outer casing, or they can be separately formed and subsequently joined together. This joining can occur immediately prior to use, in which case the two elements must be separately stored or they can be joined together for storage purposes and be ready for immediate use.

[0003] During pre-launch storage when a rocket motor is ignited inadvertently by external heating, such as a spilled fuel fire, it will become propulsive before being properly aimed. When inadvertent ignition is caused by fragment impact that produces unplanned nozzle outlets, the motor may become wildly propulsive in undesired directions. And when such events produce unplanned increases of propellant burning surface area, excessive pressurization may increase the hazard to nearby personnel and property. In light of these dangers, many of today's weapon systems must satisfy certain insensitive munitions (IM) requirements focused on safe storage capabilities.

[0004] Where rocket motors are stored separately, one way that rocket motors meet IM requirements is by venting the internal pressure caused through inadvertent ignition of the propellant by discharging either the forward or aft closure of the case cylinder. This allows the propellant to burn through a now open end without generating substantial thrust in any direction and without the threat of the rocket motor exploding and spraying burning propellant and metal case cylinder fragments in numerous directions.

[0005] The prior art teaches the use of dual paths for load transfer between features of either closure or between the closure and the motor case cylinder. One such load path may be sized to accommodate relatively small loads expected during transportation and handling prior to gun launch, and the other to accommodate much larger loads encountered during launch or during rocket motor operation. Focusing on shells which may or may not include rocket motors, Hickey teaches in U.S. Patent No. 4,557,198 (1985) use of shear pins or locking rings arranged so that the high load capability load path is armed by axial acceleration during normal launch (with or without spin-up of the round) which also disarms the low capability load path. Boissiere, in U.S. Patent No. 5,337,672 (1994), teaches arming of the high capability load path and disarming the low capability load path by gas pressures produced by the round itself, the disclosure of the document covers the preamble features of claim 1. Dolan, in U.S. Patent No. 4,597,261 (1986), Panella in U.S. Patent No. 3,887,991 (1975), Tate in U.S. Patent No. 5,036,658 (1991), Koontz in U.S. Patent No. 5,155,298 (1992), Ellingsen in U.S. Patent No. 5,311,820 (1994), and Cherry, in Statutory Invention Registration H1144 (1993), teach use of thermally activated devices of similar intent. Further, Malamas in U.S. Patent No. 4,991,513 teaches use of a vent system that is closed by spin-up at launch.

[0006] As will be shown below, the safe expulsion of either closure can also be accomplished through the use of a low shear retaining means positioned between components of the closure or between the closure and the rocket motor case cylinder and a high capability load path that is disarmed until subjected to gun pressure. Should the propellant be inadvertently ignited, the low shear retention means will shear under relatively low internal pressure and allow the entire closure, or a portion thereof, to disengage from the case cylinder. Thus, the internal pressure induced by inadvertent ignition will vent without the dangers associated with premature propulsion or explosion.

[0007] As will further be shown below, advantageous use of gun pressure to arm a high capability load path may be combined with a further use to diminish the inert -non-propeliant-weight of the gun-launched projectile.

[0008] Rocket motors are used to propel a payload. The amount of payload that can be propelled, as well as how fast and how far, are substantially affected by the weight -or mass- of the rocket motor components themselves. For the most demanding mission performance requirements, rocket motor designers focus intently on minimizing the inert weight of the motor itself.

[0009] Some rocket motors are intended for use in gun-launched projectiles, either in a "sustain" mode that diminishes losses of velocity or range due to one friction, or in a "boost" mode that increases the velocity beyond what is imparted by the gun pressure and gun tube length. In the prior art relating to such applications, the high pressures and accelerations imparted to the projectile during gun launch demand significant increases in the rocket motor inert weight - beyond what would otherwise be needed for motor operation alone.

[0010] In addition, the gun accelerations may threaten the integrity of the propellant charge itself unless great care is exercised over its configuration and means of support. Accelerations imposed within the gun tube upon gun-launched projectiles are hundreds - even thousands - of times larger than those for rocket launched projectiles.

[0011] There are two types of solid propellants for rockets. In one type, which consists of compressed powder, virtually the entire cumulative surface area of all the particles is available for combustion immediately upon ignition. In the other type, the fuel and oxidizer particles are bound together by a rubber matrix forming a composite which becomes solid after a cure protocol of thermal or other character. With the composite propellants, the burning surface area is readily controlled by adjusting the shape of the solid material and the burn rate features of the formulation. During the burn of a compressed powder propellant, vastly higher operating pressures prevail than during burn of a like quantity of composite propellants. It follows that compressed powder propellants are generally used only where the gun barrel can be used to withstand the high pressures. When the propellant is to burn after the rocket leaves the gun, it is generally a composite propellant.

[0012] The thermal expansion characteristic of composite solid propellants is typically an order of magnitude larger than that of the enclosing or containing structure. A 38°C (100° F) operating temperature range therefore produces a volume change of about 2%. Unless the configuration and support arrangement allow deformations to occur, thermal stresses in the propellant may cause fractures, undesired increases of burning surface area, and disasters upon ignition. Common provisions for thermal expansion include a central axial perforation for propellant grains bonded on their outer circumferential surfaces to cylindrical vessels, and completely free outer surfaces for propellant grains bonded at either their forward or aft ends to vessel closure features.

[0013] The tensile and shear strengths and elastic moduli of typical propellants are minuscule in comparison with the containing structure. For this reason, departures from a hydrostatic stress state during gun launch are accompanied by large deformations. At high forward acceleration, the propellant grain tends to completely fill the available volume of the aft end of the containing vessel. For a free-standing grain supported at its aft end with an unbonded circumferential surface, a 10,000 g environment and a 43 cm (17 inch) axial length lead to a 68.948 MPa (10,000 psi) hydrostatic compression at the support.

[0014] During gun launch, alternatives to the aft end support arrangement for the propellant grain are grave threats to its integrity. Indeed, at acceleration levels typical of gun launches, neither the bonded circumferential surface of an axially perforated propellant grain nor an unperforated grain with a bonded forward end is stiff enough to eliminate the aft end support mode unless there is a great deal of empty space within the motor.

[0015] It follows that virtually the entire force that accelerates the propellant grain during gun launch is applied by direct bearing through its aft end. It also follows that in a 43 cm (17 inch) long propellant grain of a typical propellant, the bearing stress will be 68.948 MPa (10,000 psi) at an acceleration of 10,000 g's. It follows also that the circumferential surface of the propellant grain will expand to fill the cylinder, imposing a radial pressure varying with depth (hydrostatically) from 68.948 MPa (10,000 psi) at the aft end to zero at the forward end.

[0016] Therefore, during gun launch, the case cylinder experiences tension in the hoop direction due to internal pressure that may well be several times larger than the operating pressure later in flight, when the propellant burns. Moreover, during gun launch, the axial force needed to accelerate the payload, forward of the rocket motor, must be carried around the propellant grain, by axial compression in the rocket motor case, which must be proportioned so that buckling does not occur.

[0017] The buckling load for an axially compressed thin cylinder depends on its radius, thickness and length, and upon a single material property, the modulus of elasticity, at the actual imposed effective stress level. When the material "yields", the modulus decreases from the initial value, Young's modulus, to zero eventually (for ductile metals). The effective stress (von Mises yield criterion) under the combined hoop tension and axial compression stress state imposed during gun launch can be as much as 73% above the hoop or axial stress, whichever is larger. Effectively, the material yields under the mixed tension and compression condition at a far lower stress level than if either stress were acting alone, and the modulus of elasticity - and the buckling load - are thereafter much reduced. Thus, the thickness needed to assure a suitable safety factory is much higher than would be deduced for either the internal pressure or axial force alone.

[0018] In recent years, efforts to overcome the above-described behaviors of both the propellant and the case cylinder have turned to admitting the gun pressure to the interior of the rocket motor case. Paget, in U.S. Patent No. 3,349,708, discloses several embodiments of a firearm launched rocket projectile that contains a solid fuel and permits gun bore gases to enter within the aft end. Paget is concerned with keeping the casing thin and suggests this can be achieved using passageways that distribute equal gun bore pressures on both the inside and outside of the projectile. The gun propulsion gases must also come into contact with the solid fuel used by Paget as that is the source of fuel ignition. Pins or springs hold passageways open to initially receive gun propulsion gases with such passageways being closed once the projectile exits the bore of the arm.

[0019] Another approach has included filling the internal free volume with a soft-extrudable fluid, rubber or otherwise. Thus, the fluid moves in and out of the rocket motor, through the nozzle throat orifice, as the storage temperature changes, and the nozzle exit cone becomes a reservoir for excess fluid. The fluid is ejected when the propellant is ignited.

[0020] Admitting the gun pressure to the interior of the rocket motor, with the fluid void-filler, has both obvious and subtle implications. Among the obvious is that unless the exterior surface of the rocket motor is also exposed to gun pressure, the case cylinder will have to accommodate as much as 413.69 MPa (60,000 psi) internal pressure, or more - an order of magnitude above the usual range of rocket motor operating pressures. To accomplish this, the obturator, the sliding seal between the projectile and the gun tube that prevents the gun pressure from escaping around the projectile, is moved from the aft to the forward end of the rocket motor. It follows that, for the quasi-static situation at maximum acceleration, the differential pressure across the case cylinder wall is external pressure of varying magnitude, reflecting the hydrostatic gradient in the propellant grain. Further, the axial compression in the case cylinder disappears because the accelerating force for the payload is applied directly to the forward closure.

[0021] The subtle implications reflect the dynamic situations as the gun pressure rises rapidly upon ignition, and as the gun pressure disappears when the obturator passes out of the gun bore. At the outside, because the orifice into the rocket motor is quite small, the intensity of the gun pressure applied to its interior lags the pressure intensity applied to the exterior. This threatens to buckle the case if the duration of the lag is large enough. Also when the obturator clears the gun bore, the small nozzle orifice prevents an instantaneous drop of internal pressure after the external pressure disappears. This threatens to burst the case unless it has been made thick enough to withstand the gun pressure level - acting alone - that prevails immediately before the obturator clears the gun bore.

[0022] Gun-launched rocket motors are obviously limited in their outside diameter by the size of the gun bore from which they are fired. Thus, given usual propellants and rocket motor nozzles, greater range or velocity is achieved for the projectile by configuring the rocket motor such that it can hold a maximum amount of propellant.

[0023] The volume of propellant in gun launched rocket motors is maximized when the interior diameter of the rocket motor case cylinder is maximized by making the case cylinder as thin as possible, However, the case cylinder must be thick enough to accommodate gun launch loads, and, when gun pressure is allowed within the case cylinder, the pressure differentials between the inside and outside of the case cylinder, not only at maximum levels, but as the gun pressure rises early during launch and falls as the rocket motor exits the gun bore. Rocket motors designed according to the prior art must therefore survive gun launch loadings that are frequently far more severe than the later loadings during rocket motor bum. This requires thicker structures which diminish the volume available for propellant, and which increase the inert weight of the motor, thereby diminishing the attainable range or velocity of the projectile.

[0024] Thus, an advancement over the prior art is achieved by introducing rocket motor configuration features that diminish the net loads that the rocket motor case cylinder must be designed to withstand during gun launch, thereby diminishing the inert weight and increasing the available propellant volume while also providing an insensitive munitions case and closure design for a gun-launched rocket motor.

[0025] The present invention provides a rocket motor comprising:

a propellant enclosed by a casing having a cylindrical region, a closed forward end and an aft assembly, including an aft closure member, provided with a central opening, secured to said casing within said cylindrical region;

a nozzle assembly and

a propellant igniter assembly mounted within said motor,

characterised in that a sliding piston assembly is slidably retained within said aft assembly and said casing so as to be movable between an at rest position adjacent said aft assembly and a maximum pressure position forward of said aft assembly in which the propellant is axially compressed to radially expand the propellant toward said casing;

in that the nozzle assembly is slidably mounted within a central bore of said sliding piston assembly so as to be movable between a forward vent path defining position and an aft vent path closing position;

and in that a burn path structure is arranged in combination with said sliding piston assembly and includes at least a sheet insulator positioned between a portion of an aft face of the propellant and a forward face of said sliding piston assembly so that abnormal propellant bums will propagate along an aft interface of said sheet insulator and normal propellant bums will propagate along a forward interface of said sheet insulator.

[0026] It was important to develop an approach for constructing a rocket motor that would not only produce the optimum results desired of getting the payload delivered to an appropriate point but do so in a way that would increase the range of the entire rocket, and prove the ability of the rocket motor to withstand the launch sequence, provide a way to accommodate size variations of the solid propellant as temperature conditions vary, while the rocket motor is being transported or stored, and incorporate in the insensitive munition capability by having the closures to the rocket motor closed but shearably closed.

[0027] In order to accomplish the latter, the present invention includes a variety of coupling techniques that include both low capability shear features to permit the rocket motor to be rendered relatively harmless should the solid propellant inappropriately ignite while being stored or transported, thus rendering the munition insensitive and high capability shear features armed by the gun pressure environment, that provide for the substantially higher loads imposed during normal operation.. Further, the present invention involves a redesigned interior for the motor itself to provide an interior environment controlled movable piston. This movable piston will not only accommodate volume changes due to temperature variations that can affect the solid propellant, but also permits the construction of the rocket motor from thinner and lighter materials. By constructing the motor this way, not only is the available volume for propellant increased but the overall inert weight is reduced, both of which tend to increase the range and effectiveness of the rocket motor itself. In addition, the new designed interior will accommodate the substantial gun pressures associated with gun launched projectiles and enables a rocket motor structure design with the ability to withstand a dramatic rapid rise and dramatic sudden fall in pressure associated with gun launched rockets.

[0028] The present invention develops a plurality of internal compression chambers which are connected to the bore of the gun by orifices designed to have the gun pressure arriving and each being substantially equal in magnitude. Further, the use of the obturator at the forward end of the rocket motor area on the rocket, in conjunction with the internal compression chamber, provides a way to minimize the difference between internal and external pressures which vary rapidly as the rocket progresses down the gun bore, Moreover, nearly the full gun pressure applied to the inner surface of the forward closure provides the accelerating force for the payload farther forward. The axial force in the case cylinder is reduced to merely the low level required to accelerate the aft closure and other features farther aft, acting in axial tension. The present invention is constructed and designed so that the materials used for the structure, preferably an 18 Ni 300 Maraging Steel, will have sufficient capacities, for the thicknesses of the parts used, to resist all imposed loadings with ample safety margins, thereby providing effective structure for the rocket motor.

[0029] Other objects, features, and characteristics of the present invention will become apparent upon consideration of the following description with reference to the accompanying drawings, all of which form a part of the specification, and wherein like reference numerals designate corresponding parts in the various figures.

FIG. 1 is a partially elevational and partially cross-sectional view of a rocket incorporating a rocket motor according to the present invention;

FIG. 2 is a cross-sectional view of another embodiment of an improved rocket motor in an at rest condition;

FIG. 3 is another view of the rocket motor of Fig. 2 within a sliding piston moved to a maximum pressure condition;

FIG. 4 is an enlarged partial view of the aft end of the rocket motor shown in Fig. 2;

FIG. 5 is an enlarged partial view of the aft end of the rocket motor shown in Fig. 3; and

FIG. 6 is an enlarged cross-sectional view of a portion of Fig. 4.

[0030] Figure 1 shows a rocket, generally indicated at 1, that includes a forward end 2, that can contain some payload, such as, for example, a guidance system and an explosive charge, and an aft rocket motor, generally indicated at 3, that is shown in partial cross-section. Included at the back end is a nozzle assembly, generally indicated at 130, and finds 4 are shown as being pivotably attached to the rearmost portion of the rocket motor 3.

[0031] This rocket 1 is designed to be launchable by a gun or other similar weapon. In addition, the present invention hereafter focuses primarily with respective to insensitive munition (IM) systems that will be disarmed by exposure to gun pressure and an approach to reduce overall rocket motor weight while retaining essential structural integrity.

[0032] During gun launch, the rifling within the gun bore, and the torque transmitted through the obturator, cause the projectile to spin rapidly as it exits the tube. The high compression at the interface between the case cylinder inner surface and the propellant grain insulator, induced by admitting gun pressure to the interior of the rocket motor, is more than sufficient to allow the needed spin-up torque increment to be transmitted by friction to the propellant grain.

[0033] Turning now to the next embodiment, specific reference to Figs. 2-6 shows an improved rocket motor 300. Figs. 2 and 4 show that rocket motor in an at rest condition as initially built and, in particular, an enlarged view of a portion of the aft end is shown in Fig. 4. Figs. 3 and 5 show the rocket, and in particular an enlarged partial view of the aft end, at peak acceleration where pressures are at a maximum within the bore of a launch weapon.

[0034] Rocket motor 300 includes a forward end, generally indicated at 302, an aft end, generally indicated at 304, an outer case 306 that encloses propellant or propellant grain 308.

[0035] An aft closure assembly, generally indicated at 310, includes an aft closure member 312 mounted within and welded at 399 to the aft end of case 306. A nozzle assembly is generally indicated at 314, a sliding piston is generally referenced at 316 and an igniter assembly is generally shown at 318. As is true of the foregoing embodiments, suitable flight control fins and a rotatably mounted attachment housing therefor (not shown) can be mounted at the aft end 3.04, using an annular bearing race 320 provided in the aft closure member 312 so that such fins mounted in the housing can deploy by swinging outwardly and the housing can spin, as is both necessary and appropriate, once the rocket leaves the bore of the launch weapon.

[0036] With reference to Figs. 2 and 4, and principally Fig. 4, the aft closure member 312 is provided with an internal cylindrical bore 322.

[0037] The sliding piston 316 includes a main cylindrical body 330 having an external or outer surface 452 and an internal chamber 332 and a sloping interior rear surface 334 to which an exit cone 336 is fixed by conventional techniques including having the exit cone 336 screwed and, in some cases, glued to the sliding piston 316. The internal chamber 332 is defined by an aft wall 338, and a cylindrical interior that is formed by an aft cylindrical interior wall 340, a forward cylindrical wall 342, that has a larger internal diameter than the aft cylindrical wall 340, and a tapered interconnecting wall 344 that extends therebetween. The forward cylindrical wall 342 can, although need not necessarily, be provided with an adhered rubber sheet insulator extending there about as is indicated at 346.

[0038] The sliding piston 316 also includes a flange 350 that extends radially outwardly from the cylindrical body 330 to engage the inner surface of case 306. Three seal components including outboard aluminum rings 352 and 356 and a centrally positioned rubber O-ring 354, are similar to those previously described. The aluminum rings 352 and 356 are provided to maintain the integrity of the O-ring 354 and to keep it from extruding during movement of the sliding piston 316. These seal components are also provided at the outer periphery of flange 350 to provide the sliding contact between the outer periphery of that flange 350 and the internal surface of case 306 as the piston 316 moves from an aft position to a forward position, that is from a position shown in Fig. 2 to that shown in Fig. 3, as the rocket is internally pressurized during gun launch, and after the propellant or propellant grain 308 is compressed axially.

[0039] The radially extending flange 350 has a rear or aft surface 360 and a forward surface 362. A hard plastic insulator 370 is mounted to forward surface 362 and in turn a tapered rubber insulator 372 is mounted to the hard plastic insulator 370. The hard plastic insulator 370 has a tapered cross sectional shape that increases from the interior toward the exterior with its thickest dimension being adjacent case 306. The tapered rubber insulator 372 is characterized by a tapered shape opposite to that of the hard plastic insulator 370 in that its largest dimension, in the section that is tapered, lies adjacent the nozzle assembly 314 and then tapers, in an outward direction, down to its smallest dimension at the point where the insulator is formed with a triangular shaped corner portion as shown at 374 that has an interior angled surface 378.

[0040] Nozzle assembly 314 is comprised of a forward nozzle insulator 380, an aft nozzle insulator 382 adhesively bonded to a tungsten throat insert 384 but not to each other, and an annular nozzle seal 386 that includes a lip seal 388 extending or projecting radially outwardly from the aft edge and adhesively bonded to the aft nozzle insulator 382. The forward and aft nozzle insulators, 380 and 382, respectively, are given a tongue and groove interlocking structure, as shown at 390 to minimize raidation damage to the rubber sheet insulator 346 on the sliding piston 316.

[0041] The aft nozzle insulator includes an angled aft surface 392 and has a cylindrical outer surface, shown by dotted line 394, and a series, preferably three, of outwardly projecting ribs 396 that engage the aft cylindrical wall 340 of the sliding piston 316. When three such ribs are employed they can be spaced 120° apart. Consequently there is a gap between aft cylindrical wall 340 and outer surface 394. Similarly, there is a gap 398 between the forward cylindrical wall 342 and the outer cylindrical surface 381 of the forward nozzle insulator 380. It should also be noted that the interior of both the tapered rubber insulator 372 and the hard plastic insulator 370 terminate at gap 398 and define the forward end portion of gap 398.

[0042] As shown in Fig. 6, case 306 serves as the outer container for the rocket. Inboard of the interior of case 306, forward of the hard plastic insulator 370 is a void space 400 and then an extension 402 of the tapered rubber insulator 372. A shoulder 404 is formed on the interior side of extension 402 and mounted on inside extension 402, in series, are a bleeder cloth layer 406 that extends along a portion of the extension 402 with the bleeder cloth layer ending with a cylindrical inhibitor 408 that has a teflon tape layer 410 covering both its inside and outside surfaces. Inboard of the bleeder cloth layer 406 is a cylindrical rubber type insulator 412 with a polymer or similar type liner, 414 bonded to the propellant 308 through an adhesive, that covers and extends around the full outer surface of the propellant grain 308 forward of the angled surface 378. From Fig. 2 it can be seen that liner 414 extends around propellant 308 and that extension 402 extends along case 306 almost to a point adjacent the forward end 302.

[0043] It should be understood that the exact materials used to surround and insulate the propellant grain 308, their arrangement and dimensions may vary depending upon the type of propellant used and that these elements will be known to those skilled in this art.

[0044] A rubber sheet nozzle insulator 420, shown in Fig. 4, extends across the aft end of the propellant 308 and along the forward surface 376 of the tapered rubber insulator 372, along the forward surface 422 of the forward nozzle insulator as well as along the angled inner surface 424 thereof. The rubber sheet nozzle insulator 420 covers the angled forward inner surface 426 of the tungsten throat insert and stops at a point adjacent the narrowest part of the nozzle throat 385 where the rubber sheet nozzle insulator 420 is sealed by an inhibitor 428 formed from liquid rubber that is poured in place and will cure at room temperature. Between sheet insulator 420 and the tapered rubber insulator 370 an additional bleeder cloth 432 is shown as extending through a portion of the region between the angled or beveled surface 378 and the annular gap 398. This bleeder cloth 432. may have an annular form or be comprised of strips. The region along the aft side of rubber sheet nozzle insulator 420 where bleeder cloth 432 is positioned is shown at "A" in Fig. 4. The aft surface of the rubber sheet nozzle insulator 420 is suitably bonded to a portion of surface 376 and to surfaces 422, 424 and 426; the forward side of the rubber sheet nozzle insulator 420 contacts and is secured to the aft surface of propellant 308. Gases resulting from an inadvertent or abnormal bum, initiated by external heating of case 306, therefore propagate and vent gases aftward through bleeder cloth 406 or along the liner 414, across the unbonded prppellant/insulator surface 378, to the aft of or, in view of the figures, the right side of the rubber sheet nozzle insulator 420, and escape through annular gap 398 without penetrating between the rubber sheet nozzle insulator 420 and the forward nozzle insulator 380. During normal bums, which initiate at the aft end of the propellant 308, the burn path can proceed along the forward side of the rubber sheet nozzle insulator 420. Both of these burn sequences are more fully described below. Techniques for bond surface preparation and the selection of adhesive formulations, compatible with propellant and insulator materials, which will assure vent path functions as herein described, are well known to those skilled in this art.

[0045] Consequently, as shown in the figures, the propellant 308 rests against the above noted surfaces and a conical portion extends to the nozzle throat.

[0046] The rubber sheet nozzle insulator 420 also extends across and blocks the entrance to gap 398. With reference to Fig. 6, the rubber sheet nozzle insulator 420 begins adjacent the corner defined between the surface 378, which lies next to and unbonded to propellant 308, and bonded surface 376. Provided as part of the outer peripheral part of rubber sheet nozzle insulator 420 is an inhibitor area 430, that extends radially inwardly a limited distance. On the aft side of this area lies a section of bleeder cloth 432 that also extends radially inwardly for another limited distance as shown at A in Fig. 4. This bleeder cloth 432 is preferably formed from a fabric woven from a synthetic material, such as, for example, polypropylene, nylon, or other low melt temperature fiber. From the point where bleeder cloth 432 ends the rubber sheet nozzle insulator 420 is attached to the remaining portions of forward surfaces 376,422, 424 and 426 in a way that will allow abnormal bums to proceed on the aft side thereof and normal burns on the forward side thereof.

[0047] By employing these structural features this rocket motor design satisfies certain insensitive munitions (IM) requirements, that help assure safe storage, by employing inter-related features of the insulators 370 and 372 positioned forward of the sliding piston 316, the sliding piston 316 itself, the nozzle assembly 314 and its interaction within the sliding piston 316, the rubber sheet nozzle insulator 420, the limited region of bleeder cloth 432 and their bonded relationships that will allow a sequence of events to proceed that will assure IM protection as well as safe, faultless normal propellant ignition.

[0048] How this system operates will now be described and the foregoing IM protection will become clear. As noted above, the rubber sheet nozzle insulator 420 overlies a section of bleeder cloth 432 positioned along a limited region of forward face 376 of the tapered rubber insulator 372 adjacent the outer portion of that face 376. In an abnormal burn or ignition situation, such as could occur due to external case heating, it is proposed that the burn path be on and extend along the aft side of the rubber sheet nozzle insulator 420. With such an abnormal burn starting on the exterior of the propellant, the burn or fire path will propagate along the interior surface of extension 402 and then along the beveled or sloping surface 378. When the burn reaches the outer peripheral end of the rubber sheet nozzle insulator 420 there will be sufficient heat to easily melt the bleeder cloth 430, due to the gases being generated at thousands of degrees above the melt or decomposition temperature of bleeder cloth 432. As the bleeder cloth 432 melts or decomposes a space or cavity is opened on the aft side of the rubber sheet nozzle insulator 420. Due to this cavity the burn or fire path will propagate radially inwardly and as it moves it will peel the rubber sheet nozzle insulator 420 away from the forward face 376 of the tapered rubber insulator 372 until the peeling process reaches the cylindrical gap 398. At this point a vent path, that starts with the cylindrical gap 398, is opened. The accumulating gases will flow aft through gap 398 and then into the open space about nozzle seal 386 and then along the cylindrical space between outer surface 394 and aft cylindrical wall 340. By having gases vent through gap 398, the burn will be kept away from the nozzle assembly 314/propellant 308 attachment area.

[0049] The vent path will desirably extend to the atmosphere but that path remains blocked by the igniter assembly 318. The bond between the igniter assembly 318 and the interior conical surface of exit cone 336 is provided by a conventional soft and frangible adhesive thereby making this bond one that can break and yield. When a sufficient pressure builds the entire igniter assembly 318 will be expelled by the accumulated gases thus fully opening the vent path out of the aft end of the rocket motor 300 to the atmosphere. Subsequent gases being generated by the abnormal burn will be exhausted along the same vent path.

[0050] The annular space defined by cylindrical gap 398 and the space around outer surface 394 is, shown as being about ten (10) times the size of the nozzle orifice at the nozzle throat. By adjusting this ratio, the thrust resulting from abnormal burn can be varied to provide the desired level of initial protection.

[0051] Since the thin rubber sheet insulator 346, overlying forward cylindrical wall 342, is poor protection for that wall against rocket motor propellant gases flowing at high velocity, the gases will penetrate this thin wall 342 very quickly, resulting in the destruction of at least a portion of the thin wall 342 and the ejection of the aft portion of the sliding piston 316 together with the nozzle assembly 314, exit cone 336 and the whole igniter assembly 318, all of which depart as a unit. Thereafter, the exhaust area available will be so large that the propulsive force will be quite small.

[0052] By having the bum, and thereby the vent path functioning on the aft side of the rubber sheet nozzle insulator 420. the IM requirement of having a safety release capability built into the rocket motor will have been achieved. The aft side vent path also assures that the gases resulting from an abnormal propellant burn will not pass through the nozzle throat but, rather, around the outer periphery of the nozzle assembly 314.

[0053] The igniter assembly 318 is held in place by a frangible adhesive as noted previously. Included as part of the igniter assembly 318 is a forward nozzle 448 and a main body 442 which contains a conventional time delay ignition train 444 positioned aft of the nozzle 448.

[0054] With reference to Fig. 4 it can be noted that another annular gap 450 is defined between the exterior surface 452 of sliding piston 316 and the internal bore 322 of the aft closure member 312. During normal operation, the rocket motor 300 will be launched, as discussed previously from a launch weapon such as a five inch naval gun. As a result of such a gun launch, and as gun gases are generated within the bore of the gun, by the gun propellant(not shown) aft of the rocket motor 300, such gun gases will enter annular gap 450 and strike against and pressurize the aft surface 360 of the flange 350. The imposing of such axial forces on the sliding piston 316 moves that sliding piston 316 from an at rest position, shown in Figs. 2 and 4, toward and ultimately to the maximum pressure position shown in Figs. 3 and 5 as the propellant 308 deformes radially to completely fill the void space 400 shown in Figs. 4 and 6.

[0055] As initially constructed, aft surface 360 of flange 350 will not fit exactly against the forward surface 454 of the aft closure member 312. The axial force associated with the gun propellant gases entering annular gap 450 and striking the aft surface 360 of flange 350 will move the sliding piston 316 forward, thereby creating an enlarged aft cavity 456. As the sliding piston moves forward the outer edge of flange 350 slides along the inside surface 458 of case 306, guided by seal components 352 to 356. The axial force on sliding piston 316 is transmitted through the hard plastic insulator 370 and the tapered rubber insulator 372,compressively loading propellant 308. The tapered rubber insulator 372 deforms as shown in Fig. 2, with a portion of the interior thereof being moved toward and into gap 398 and possibly even along forward surface 424 of the forward nozzle insulator 380.

[0056] The changing shape of the tapered rubber insulator 372 will cause the initially planar aft surface of the propellant, as it is compressed, to become dished or formed with a slight convexity, shown in Fig. 5, thereby applying force to forward nozzle insulator 380. This force causes relative movement between the internal chamber 332 of the sliding piston 316 and the nozzle assembly 314 due to a combination of high inertia loading associated with launch and the counter compressive forces acting on the nozzle assembly 314 from propellant 308. This relative movement will position the nozzle assembly 314 aftward within the internal chamber 332, as is also shown in Fig. 5.

[0057] When the nozzle assembly 314 is fully seated within chamber 332 surface 392 of the aft nozzle insulator 382 (Fig. 4) will lie in contact with surface 338 of the sliding piston 316. As this relative movement takes place the lip seal 388 will contact and grip a portion of the forward part of cylindrical wall 340 thereby providing a holding force to maintain the moved position of the nozzle assembly 314 within internal chamber 332.

[0058] The combined effect of such movement of the nozzle assembly 314 and the compression and flow of the material forming the tapered rubber nozzle insulator 372 blocks the IM vent path previously described.

[0059] As gun-launch concludes, gun gases that entered the motor 300 through annular gap 450 will depart through that same annular gap 450 and forces acting on the aft surface 360 of the flange 350 of the sliding piston 316, and within cavity 456, will progressively lessen. Compressive forces previously acting on propellant 308 will likewise progressively decrease and as these forces decrease, pressures interior and exterior of the case 306 will also progressively decrease. As a consequence, case 306 will have been able to tolerate the rise and fall of interior and exterior pressures associated with a gun-launched rocket.

[0060] As forces decrease, the axial force acting to compress the tapered rubber insulator 372 also lessen allowing it to return toward its uncompressed condition. As the tapered rubber insulator 372 returns to its former thickness, which was the largest part of its tapered shape, such movement will initiate aftward movement of the sliding piston 316 toward the aft closure member 312 and separate the bond provided between the propellant 308 and the forward surface of the rubber sheet nozzle insulator 420, to provide a path for burn propagation during normal ignition which will follow, with the aft surface of the latter remaining adhered to most of the forward face 424 of the forward nozzle insulator 380 and to surface 426 of the tungsten throat insert 384. At this point the propellant 308 is ready to be ignited for a normal burn.

[0061] The gun gases initiate burn of the time delay ignition train 444 within the igniter assembly 318, so that at a desired interval after the projectile leaves the bore of the launch weapon an igniting flame passes through inhibitor 428 and into contact with propellant 308. When this occurs, the rubber sheet nozzle insulator 420 will be adhered to the forward surfaces 424 of the forward nozzle insulator 380 and the angled forward surface of the tungsten throat insert 384. With those connections intact, normal burning of propellant 308 can proceed on the forward side of the rubber sheet nozzle insulator 420.

[0062] As propellant 308 ignites, the sliding piston 316, together with the now attached nozzle assembly 314 will slide aftward until the flange 350 again contacts the aft closure member 312. As propelling forces begin to rise, heat and pressure build within the nozzle assembly 314. Due to the frangible nature of the bond holding the igniter assembly 318 in place such pressures will also break that bond thereby expelling the entire igniter assembly 318 which opens the exit cone so that a normal burn can proceed.

[0063] It should be understood that various types of bonding can be used to both hold the rubber sheet nozzle insulator 420 in its desired position and to permit both normal and abnormal propellant bums and the consequential gas transmissions to flow along forward and aft surfaces or interfaces of that rubber sheet insulator 420 to permit the burn and venting processes to proceed as discussed above.

Claims

1. A rocket motor (3, 300) comprising:

   propellant (308) enclosed by a casing (306) having a cylindrical region, a closed forward end (6, 302) and an aft assembly (310), including an aft closure member (312), provided with a central opening (322), secured to said casing within said cylindrical region;
   a nozzle assembly (314) and
   a propellant igniter assembly (318) mounted within said motor,
   characterised in that a sliding piston assembly (316) is slidably retained within said aft assembly and said casing so as to be movable between an at rest position adjacent said aft assembly and a maximum pressure position forward of said aft assembly in which the propellant is axially compressed to radially expand the propellant toward said casing;
   in that the nozzle assembly (314) is slidably mounted within a central bore (340) of said sliding piston assembly so as to be movable between a forward vent path (398) defining position and an aft vent path closing position;
   and **in that** a burn path structure is arranged in combination with said sliding piston assembly and includes at least a sheet insulator (420) positioned between a portion of an aft face of the propellant and a forward face (362) of said sliding piston assembly so that abnormal propellant burns will propagate along an aft interface of said sheet insulator and normal propellant burns will propagate along a forward interface of said sheet insulator.

2. A rocket motor according to claim 1 wherein said sliding piston assembly (316) includes a radially extending flange (350) having a front face (362) on which at least one tapered insulator (372) is mounted, said at least a sheet insulator (420) being connected to the propellant (308) and said at least one tapered insulator.

3. A rocket motor according to claim 2 wherein said at least one tapered insulator (372) is comprised of rubber.

4. A rocket motor according to claim 2 or 3 further including an additional tapered insulator (370) positioned aft of said at least one tapered insulator (372).

5. A rocket motor according to any one of claims 1 to 4 wherein said vent path (398) is positioned radially outboard of said nozzle assembly (314).

6. A rocket motor according to any one of claims 1 to 5 wherein said propellant igniter assembly (318) is frangibly mounted to said sliding piston assembly (316).

7. A rocket motor according to any one of claims 1 to 6 wherein said vent path (398) comprises an annular gap defined between an outer surface of said nozzle assembly (314) and an inner surface of said central bore (340) of said sliding piston assembly (316).

8. A rocket motor according to claim 7 wherein a portion of said sliding piston assembly (316) adjacent said central bore (340) is defined by a thinned wall that will break under abnormal burns thereby allowing the sliding piston assembly, aft of such break, to be expelled together with said nozzle assembly (314) and said propellant igniter assembly (318).

9. A rocket motor according to claim 2 or any claim dependent thereon wherein said at least one tapered insulator (372) is compressible.

10. A rocket motor according to any one of claims 1 to 9 wherein said sliding piston assembly (316) is spaced inwardly from said central bore (322) of the aft closure member (312) defining an annular chamber (450) open to the atmosphere through which said sliding piston assembly is pressured axially.

11. A rocket motor according to claim 2 or any claim dependent thereon wherein said flange (350) has a rear surface (360) and said sliding piston assembly (316) is spaced inwardly from a central bore (322) of said aft closure member (312) defining an annular chamber (450) open between said rear surface and the atmosphere.

12. A rocket motor according to any one of claims 1 to 11 further including a lock member to secure said nozzle assembly (314) in its aft vent path closing position.

13. A rocket motor (300) according to claim 1; wherein the aft closure member (312) is circular and has a cylindrical opening (322);
    wherein said sliding piston (316) includes a flange (350) radially extending to the cylindrical region and a cylindrical portion (330) extending aftward extending in said cylindrical opening;
    wherein said cylindrical portion is spaced radially inward from said aft closure member to define an axially extending open passage (450) therebetween and from at least a portion of rear surface (360) of

said radially extending flange and the atmosphere; and wherein the igniter assembly (318) is positioned within an exit cone (336) of said aft assembly so as to be operational through said nozzle assembly to ignite the propellant.

Patentansprüche

1. Raketentriebwerk (3, 300) bestehend aus dem Folgenden:

   einem Treibmittel (308), umgeben von einem Gehäuse (306), welches einen zylinderförmigen Bereich, ein geschlossenes, vorderes Ende (6, 302) und eine HeckAnordnung (310) aufweist, einschließlich eines Heckschließmittels (312), versehen mit einer zentralen Öffnung (322), befestigt an dem Gehäuse innerhalb des zylinderförmigen Bereichs;
   eine Düsenanordnung (314) und
   ein in dem Triebwerk angeordneter Treibmittelzünder (318),
   dadurch gekennzeichnet, dass eine gleitende Kolbenanordnung (316) verschiebbar innerhalb der Heckanordnung und des Gehäuses gehalten ist, um bewegbar zu sein zwischen einem Ruhezustand, angrenzend zur Heckposition und einer maximalen Druckposition im Bereich vor der Heckanordnung, in welcher das Treibmittel axial zusammengedrückt wird, bei der radialen Ausdehnung des Treibmittels in Richtung des Gehäuses;
   in welcher die Düsenanordnung (314) verschiebbar innerhalb einer zentralen Bohrung (340) der gleitenden Kolbenanordnung angebracht ist, um zwischen einer definierten Stellung eines vorderen Entlüftungsweges (398) und eines Verschlussweges einer Heckentlüftungsöffnung beweglich zu sein; und
   in welcher eine Brandweganordnung in Kombination mit der gleitenden Kolbenanordnung angeordnet ist und mindestens eine blattförmige Isolierung (420) einschließt, angeordnet zwischen einem Teil der Heckoberfläche des Treibmittels und einer Frontoberfläche (362) des gleitenden Kolbens, damit sich ein anormaler Treibmittelabbrand entlang einer Heckoberfläche der blattförmigen Isolierung propagiert und der normale Treibmittelabbrand sich entlang einer Frontoberfläche der blattförmigen Isolierung propagiert.

2. Raketentriebwerk nach Anspruch 1, worin die gleitende Kolbenanordnung (316) einen sich radial erstreckenden Flansch (350) beinhaltet, welcher eine Frontoberfläche (362) aufweist, auf der mindestens eine sich verjüngende Isolierung (372) befestigt ist, wobei die mindestens eine blattförmige Isolierung (420) mit dem Treibmittel (308) und mindestens mit einem sich verjüngenden Isolator verbunden ist.

3. Raketentriebwerk nach Anspruch 2, worin die mindestens sich verjüngende Isolierung (372) Gummi aufweist.

4. Raketentriebwerk nach Anspruch 2 oder 3, welches ferner eine zusätzliche, sich verjüngende Isolation (370) beinhaltet, hinten an der sich verjüngenden Isolation (372) angeordnet.

5. Raketentriebwerk nach einem der Ansprüche 1 bis 4, worin der Entlüftungsweg (398) radial nach außen in Richtung der Düsenanordnung (314) angeordnet ist.

6. Raketentriebwerk nach einem der Ansprüche 1 bis 5, worin der Treibmittelzünder (318) abbrechbar an dem gleitendem Kolben (316) angebracht ist.

7. Raketentriebwerk nach einem der Ansprüche 1 bis 6, worin der Entlüftungsweg (398) einen ringförmigen Abstand zwischen der Außenseite der Düsenanordnung (314) und der inneren Oberfläche der zentralen Bohrung (340) des gleitenden Kolbens (316) aufweist.

8. Raketentriebwerk nach Anspruch 7, worin ein Teil der gleitenden Kolbenanordnung (316), angrenzend an die zentrale Bohrung (340) durch eine verdünnte Wand definiert ist, welche bei anormalem Brand bricht, wodurch der gleitenden Kolbenanordnung nach dem Abbrechen ermöglicht wird zusammen mit der Düsenanordnung (314) und dem Treibmittelzünder (318) auszutreiben.

9. Raketentriebwerke nach Anspruch 2 oder einem davon abhängigen Anspruch, worin mindestens eine sich verjüngende Isolierung (372) zusammenpressbar ist.

10. Raketentriebwerk nach einem der Ansprüche 1 bis 9, worin die gleitende Kolbenanordnung (316) einen nach innen gerichteten Abstand von der zentralen Bohrung (322) des Heckverschlussmittel (312) aufweist, welches eine ringförmige Kammer (450) definiert, die zur Atmosphäre geöffnet, durch welche die gleitende Kolbenanordnung axial gepresst wird.

11. Raketentriebwerk nach Anspruch 2 oder einem davon abhängigen Anspruch, worin der Flansch (350) eine heckseitige Oberfläche (360) aufweist und worin die gleitende Kolbenanordnung (316) einen nach innen gerichteten Abstand von der zentralen Bohrung (322) des Heckverschlussmittels (312) aufweist, welches eine ringförmige Kammer (450) bil-

det, die zur heckseitigen Oberfläche und zur Atmosphäre hin geöffnet ist.

12. Raketentriebwerk nach einem der Ansprüche 1 bis 11, welches ferner ein Verschlussmittel zum Verschließen der Düsenanordnung (314) an der Schließposition des hinteren Entlüftungsweges aufweist.

13. Raketentriebwerk (300) nach Anspruch 1, worin das heckseitige Verschlussmittel (312) kreisförmig ist und eine zylindrische Öffnung (322) aufweist;
worin der gleitende Kolben (316) einen Flansch (350) aufweist, welcher sich radial in den zylindrischen Bereich erstreckt und ein zylindrisches Teil (330), welches sich nach hinten in die zylindrische Öffnung hinein erstreckt;
worin des zylindrische Teil radial von dem heckseitigen Verschlussmittel beabstandet ist, zur Bildung eines sich axial erstreckenden Öffnungsweges (450) dazwischen und von dem mindestens einen Teil der hinteren Oberfläche (360) des sich radial erstreckenden Flansches und der Atmosphäre; und
worin die Zünderanordnung (318) innerhalb eines Auslasskegel (336) der Heckanordnung positioniert ist, so dass sie durch diese Düsenanordnung zur Zündung des Treibmittels in Betrieb genommen wird.

Revendications

1. Moteur de fusée (3, 300) comprenant :

un agent propulseur (308) enfermé dans un boîtier (306) comportant une zone cylindrique, une extrémité avant fermée (6, 302) et un ensemble arrière (310), comprenant un élément de fermeture arrière (312), muni d'une ouverture centrale (322), fixé audit boîtier à l'intérieur de ladite zone cylindrique ;
un ensemble de tuyère (314) et
un ensemble allumeur d'agent propulseur (318) monté à l'intérieur dudit moteur,
caractérisé en ce qu'un ensemble de piston coulissant (316) est retenu en coulissement à l'intérieur dudit ensemble arrière et dudit boîtier, de manière à être mobile entre une position de repos adjacente audit ensemble arrière, et une position de pression maximum en avant dudit ensemble arrière, dans laquelle l'agent propulseur est axialement comprimé pour dilater radialement l'agent propulseur vers ledit boîtier ;
en ce que l'ensemble de tuyère (314) est monté en coulissement à l'intérieur d'un alésage central (340) dudit ensemble de piston coulissant, de manière à être mobile entre une position avant définissant un trajet d'aération (398) et une position arrière de fermeture du trajet d'aération ;
et **en ce qu'**une structure de trajet de combustion est agencée en combinaison avec ledit ensemble de piston coulissant, et elle comprend au moins un isolateur en feuille (420) positionné entre une partie d'une face arrière de l'agent propulseur et une face avant (362) dudit ensemble de piston coulissant de sorte que les combustions anormales d'agent propulseur vont se propager le long d'une interface arrière dudit isolateur en feuille et les combustions normales d'agent propulseur vont se propager le long d'une interface avant dudit isolateur en feuille.

2. Moteur de fusée selon la revendication 1, dans lequel ledit ensemble de piston coulissant (316) comprend une bride s'étendant dans un sens radial (350) ayant une face avant (362) et sur laquelle est monté au moins un isolateur tronconique (372), ledit au moins un isolateur en feuille (420) étant relié à l'agent propulseur (308) et audit au moins un isolateur tronconique.

3. Moteur de fusée selon la revendication 2, dans lequel ledit au moins un isolateur tronconique (372) comprend du caoutchouc.

4. Moteur de fusée selon la revendication 2 ou 3, comprenant en outre un isolateur tronconique supplémentaire (370) positionné à l'arrière dudit au moins un isolateur tronconique (372).

5. Moteur de fusée selon l'une quelconque des revendications 1 à 4, dans lequel ledit trajet d'aération (398) est positionné à l'extérieur dudit ensemble de tuyère (314).

6. Moteur de fusée selon l'une quelconque des revendications 1 à 5, dans lequel ledit ensemble allumeur d'agent propulseur (318) est monté de manière frangible audit ensemble de piston coulissant (316).

7. Moteur de fusée selon l'une quelconque des revendications 1 à 6, dans lequel ledit trajet d'aération (398) comprend un écart annulaire défini entre une surface externe dudit ensemble de tuyère (314) et une surface interne dudit alésage central (340) dudit ensemble de piston coulissant (316).

8. Moteur de fusée selon la revendication 7, dans lequel une partie dudit ensemble de piston (316) adjacente audit alésage central (340) est défini par une paroi amincie qui se rompt lors de combustions anormales permettant ainsi à l'ensemble de piston coulissant, situé à l'arrière d'une telle rupture, d'être évacué en même temps que ledit ensemble de tuyère (314) et ledit ensemble allumeur d'agent propulseur

(318).

9. Moteur de fusée selon la revendication 2 ou une quelconque des revendications dépendant de celle-ci, dans lequel ledit au moins un isolateur tronconique (372) est compressible.

10. Moteur de fusée selon l'une quelconque des revendications 1 à 9, dans lequel ledit ensemble de piston coulissant (316) est espacé vers l'intérieur dudit alésage central (322) de l'élément de fermeture arrière (312), définissant une chambre annulaire (450) ouverte à l'air ambiant, à travers laquelle ledit ensemble de piston coulissant est mis sous pression dans un sens axial.

11. Moteur de fusée selon la revendication 2 ou une quelconque des revendications dépendant de celle-ci, dans lequel ladite bride (350) présente une surface arrière (360), et ledit ensemble de piston coulissant (316) est espacé vers l'intérieur par rapport à un alésage central (322) dudit élément de fermeture arrière (312), définissant une chambre annulaire (450) ouverte entre ladite surface arrière et l'air ambiant.

12. Moteur de fusée selon l'une quelconque des revendications 1 à 11, comprenant en outre un élément de blocage pour bloquer ledit ensemble de tuyère (314) dans sa position arrière de fermeture de trajet d'aération.

13. Moteur de fusée (300) selon la revendication 1, dans lequel l'ensemble arrière de fermeture (312) est circulaire et il comporte une ouverture cylindrique (322) ;

dans lequel ledit piston coulissant (316) comprend une bride (350) s'étendant dans un sens radial par rapport à ladite zone cylindrique, et une partie cylindrique (330) s'étendant vers l'arrière dans ladite ouverture cylindrique ;

dans lequel ladite partie cylindrique est radialement espacée vers l'intérieur par rapport audit élément de fermeture arrière, pour définir un passage ouvert s'étendant axialement (450) entre les deux, et par rapport à au moins une partie de surface arrière (360) de ladite bride s'étendant radialement et l'air ambiant ;

et dans lequel l'ensemble allumeur (318) est positionné à l'intérieur d'un cône de sortie (336) dudit ensemble arrière de manière à être opérationnel à travers ledit ensemble de tuyère pour allumer l'agent propulseur.

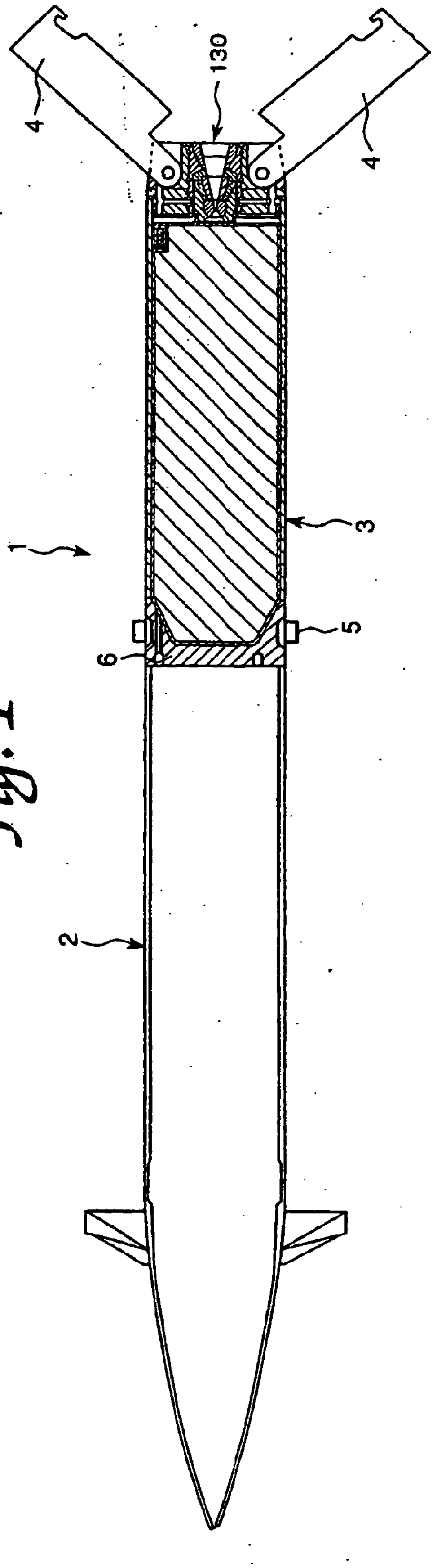

Fig. 1

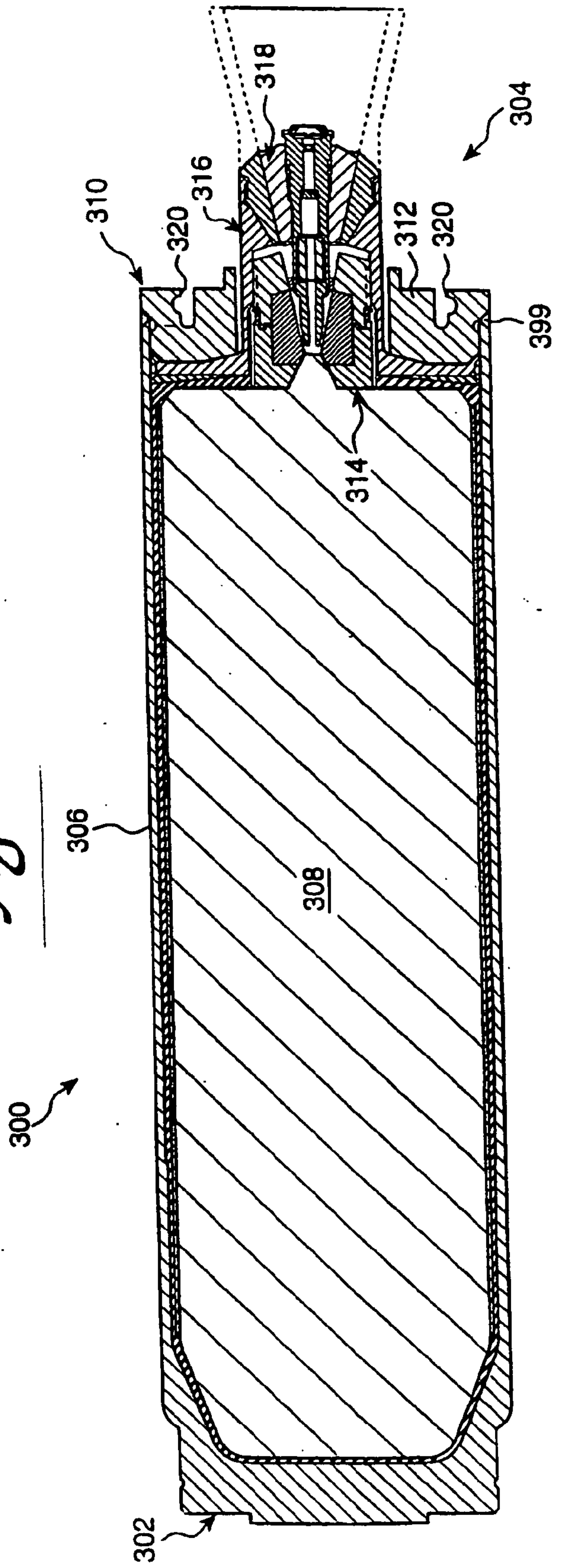

Fig. 2

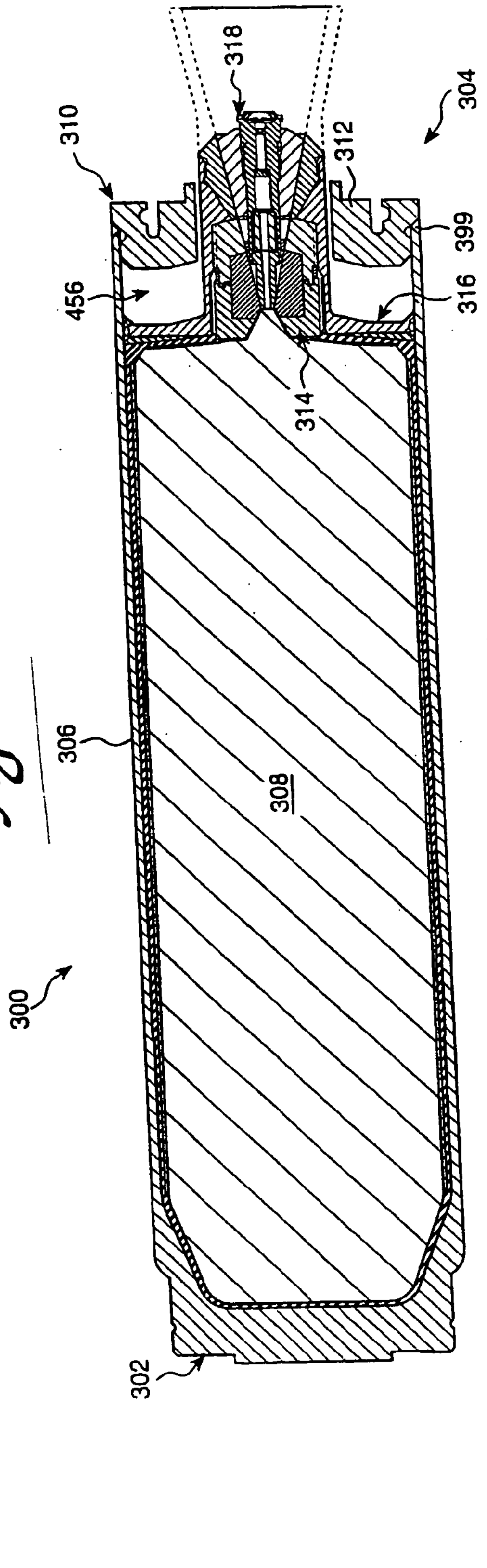

Fig. 3

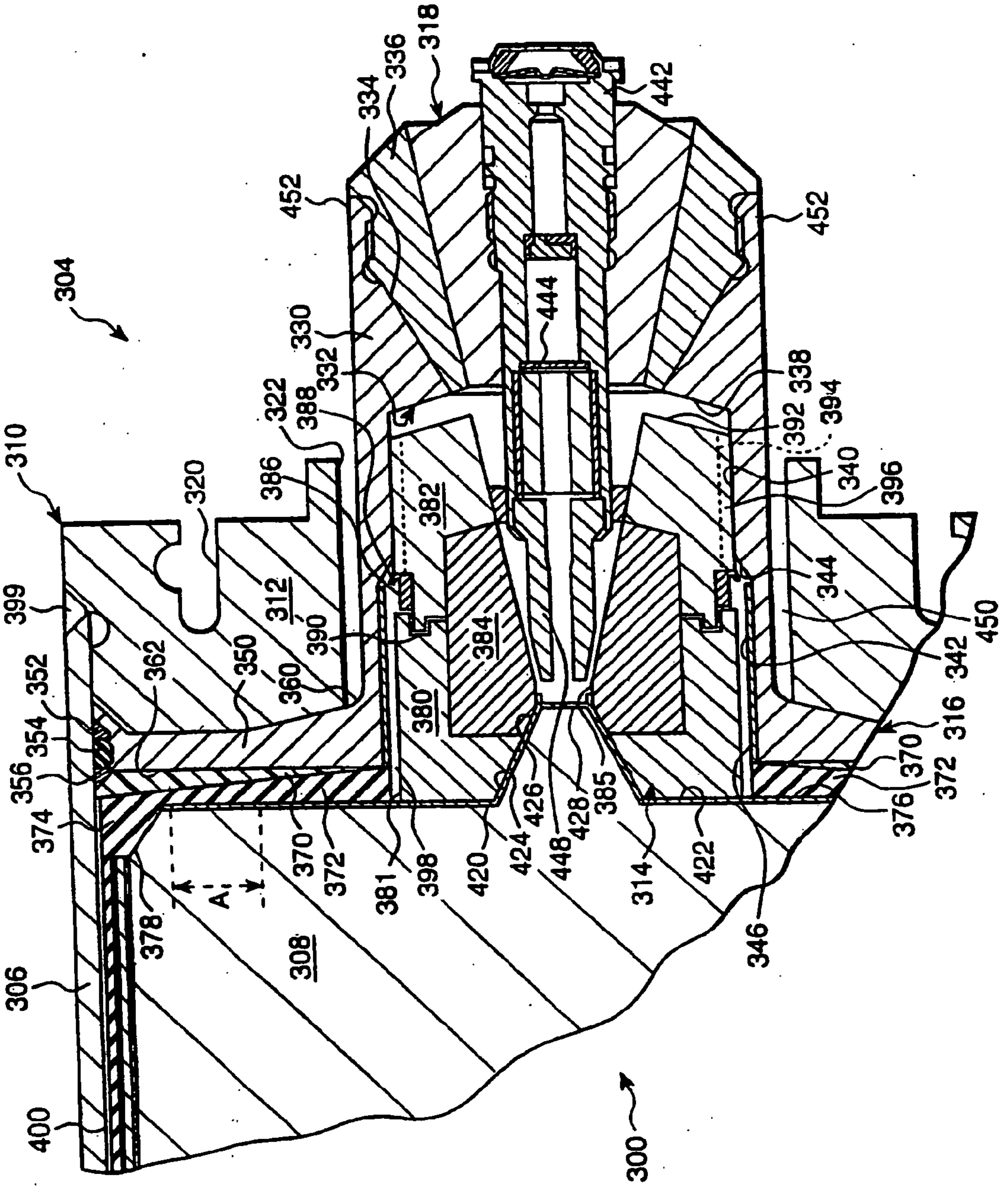

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Fig. 4

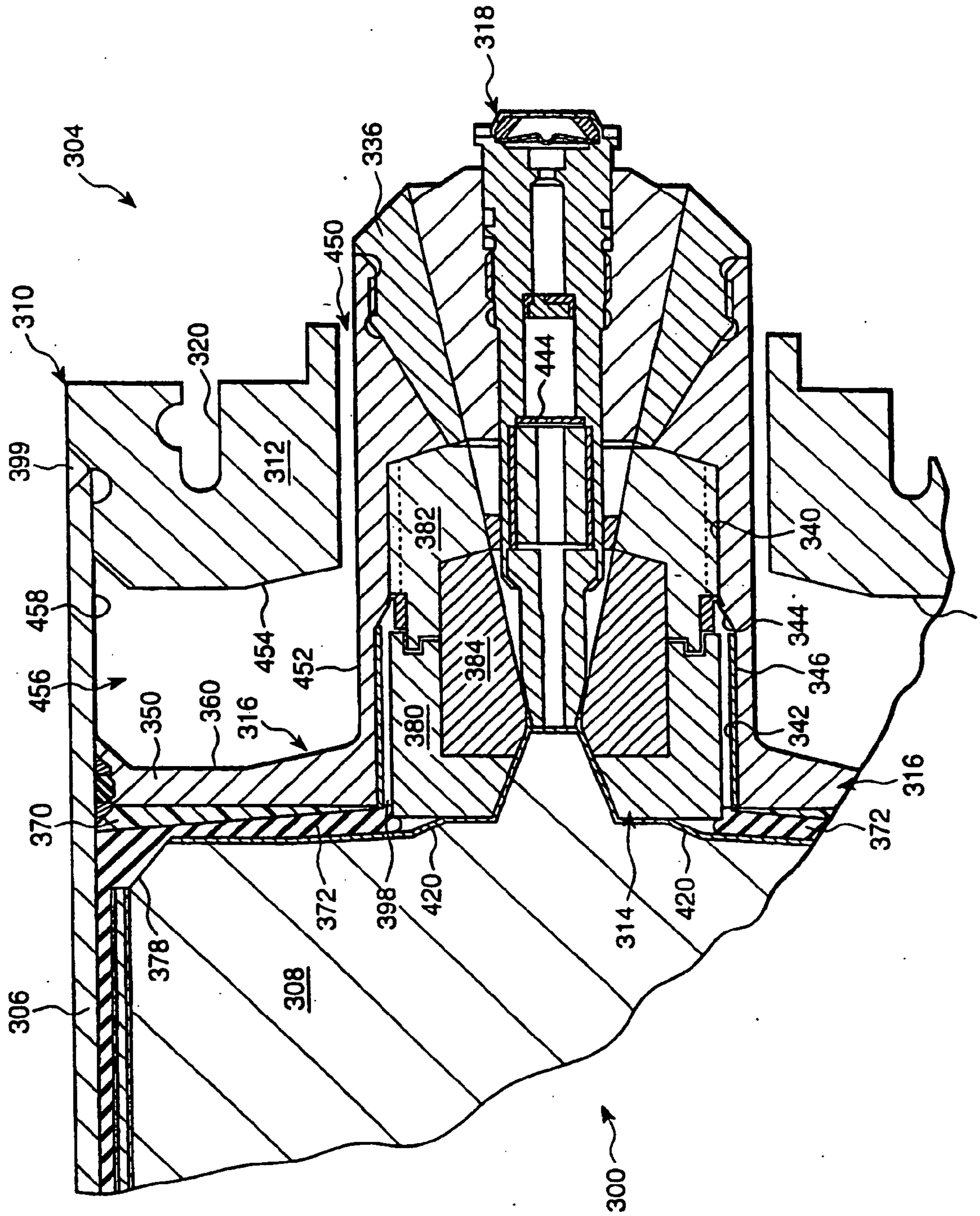
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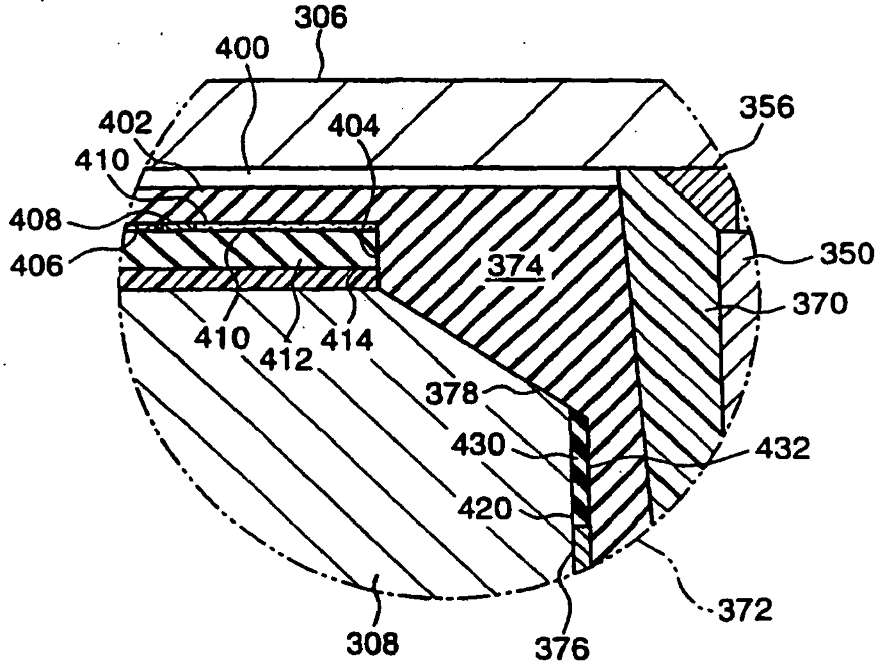
Fig. 5

Fig. 6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REFERENCES CITED IN THE DESCRIPTION

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