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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : F01B 11/02, F02B 71/00

A1

(11) International Publication Number: WO 93/01393

(43) International Publication Date: 21 January 1993 (21.01.93)

(21) International Application Number: PCT/AU92/00346

(22) International Filing Date: 10 July 1992 (10.07.92)

(30) Priority data:
PK 7151 10 July 1991 (10.07.91) AU

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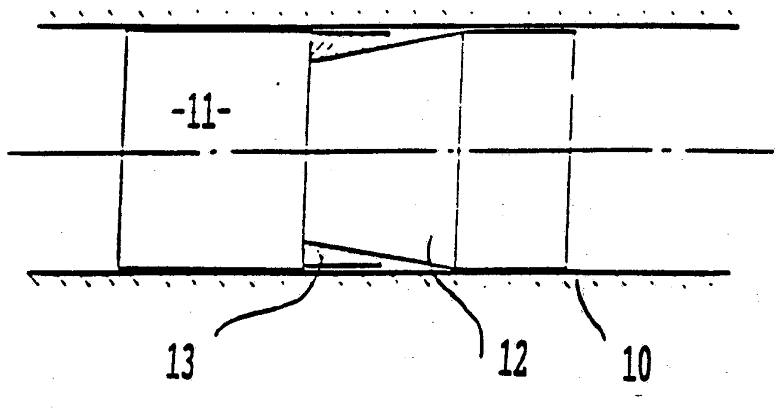
(81) Designated States: JP, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IT, LU, MC, NL, SE).

Published
With international search report.

(54) Title: PISTON MOTION CONTROL IN FREE PISTON DRIVER



(57) Abstract

A free piston mechanism comprising a compression tube (1) having a driving end and a compression end, a free piston (11) drivable within the compression tube (1) towards the compression end and adapted to compress a driver gas at the compression end of the tube (10), a driver associated with the driving end of the tube (1) and a brake (13) for restraining the piston (11) from rebounding from the compression end of the tube (10). The brake (13) is preferably in the form of a plurality of tapered shoe segments (13) acting between the piston (11) and the tube (1). Also disclosed is a buffer operatively interposed between the piston (11) and the compression end of the tube (10).

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PISTON MOTION CONTROL IN FREE PISTON DRIVER

-- BACKGROUND OF THE INVENTION --

This invention relates to an apparatus for providing piston motion control in free piston drivers. This application claims priority from our Australian Provisional Patent Application No. PK7151 filed 10 July 1991.

This invention has particular but not exclusive application to free piston drivers of the type utilized in hypersonic aerodynamic test facilities such as shock tubes, reflected shock tubes and expansion tubes, and for illustrative purposes reference will be made to such application. However, it is to be understood that this invention could be used in other applications, such as any other free piston research devices or projectile launchers such as light gas guns and other similar devices and pneumatic impact devices.

In a free piston driver, a piston, which is free to move along a tube (usually called the compression tube), is driven towards the end of the compression tube, generally by a high pressure propellant gas such as compressed air. In moving forward the piston compresses a slug of a selected gas such as helium in front of it. Typically the selected gas, generally termed the "driver gas", builds in pressure to a predetermined extent whereupon the driver gas is put to whatever end use is desired. For example, the driver gas may be used to accelerate a projectile or dynamic model, or in shock tunnel embodiments, after rupturing a diaphragm at the end of the compression tube, may be used to generate a shock wave in a working gas downstream of the diaphragm.

The diameter of the exit produced in the diaphragm or the working space for the driver gas is generally less then that of the compression tube itself. As the driver gas bleeds away from ahead of the piston, the decelerating influence of the driver gas diminishes, since there is still the original propellant gas behind the piston, but little gas remaining in front of it. The piston may therefore be propelled into violent collision with the end of the compression tube. Accordingly, the parameters of the propellant gas and the driver gas will be selected such that such collisions should not occur.

However, where the driver gas has buffered the piston and prevented a primary collision with the end of the compression tube, there is a tendency for the piston to rebound some distance back down the compression tube. At this point the propellant gas behind the piston still has considerable pressure, while the driver gas pressure in front of the piston has dropped. The result is that the piston accelerates forward, striking the end of the tube with considerable velocity in a secondary impact.

-- <u>OBJECTS OF THE PRESENT INVENTION</u> --

The present invention aims to alleviate the above disadvantages and to provide free piston driver apparatus and methods of providing piston motion control in such apparatus which will be reliable and efficient in use. Other objects and advantages of this invention will hereinafter become apparent.

-- SUMMARY OF THE PRESENT INVENTION --

With the foregoing and other objects in view, this invention in one aspect resides broadly in a free piston driver apparatus including:-

a compression tube having a driving end and a compression end;

a free piston drivable within said compression tube towards said compression end and adapted to compress a driver gas at an end of said compression tube;

driving means associated with said driving end, and

holding means for restraining said piston from rebounding from said compression end.

The holding means may take any form consistent with the function of preventing the piston rebounding from the compressed driver gas. For example, the holding means may be associated with either one or both of the piston and the compression tube and may be adapted to engage one with the other to arrest rebounding motion of the piston.

Preferably, the holding means takes the form of brake means associated with the piston and adapted to operatively engage the cylindrical inner wall of the compression tube to arrest motion of the piston. For example, the brake means may take the form of expandible shoes or bands or other forms of braking of an object slidingly engaged within a chamber. However, the brake means preferably includes wedge type brakes wherein there is provided a plurality of tapered shoe segments adapted to engage the compression tube inner wall. The shoes are preferably held in place around the piston body by a resilient restraint, to facilitate removal from and reinsertion of the piston into the tube.

Preferably, the shoes comprise a backing material suitable for bonding to friction material in a bond capable of sustaining a high shear force. The backing material may be of any suitable known material for backing purposes with it being preferred to use a metal material such as aluminium.

The friction material may be selected from any known brake type friction material. However, it is preferred that the friction material be selected such that the friction material will shear at some shear load below that capable of causing extensive damage to the free piston apparatus. Preferably, the friction material is selected from asbestos free reinforced resin based friction materials, with it being particularly preferred to use metal impregnated resin brake lining material.

The wedge type shoes are preferably engaged in corresponding ramped portions of the piston wall, the interaction of the ramped portion effecting engagement of the shoes with the compression tube wall when the piston attempts to rebound off the compressed driver gas. Preferably the ramped portions are comprised of a truncated conical machining of the piston to form an annular taper. The profile of the shoe backing material is preferably tapered to conform with the conical shape of the piston body taper. The backing material is preferably relatively flexible so as to allow for some deformation of the shoes, permitting the shoes to conform to the varying circumference of the tapered portion of the piston as the shoes in use move along the working surface of the tapered portion.

Preferably, the inner surface of the backing material in contact with the taper is provided with a low friction material such as polytetrafluoroethylene.

In order to limit the braking force of the shoes, it may be desirable to provide force limiting means to limit the normal force of the shoes on the compression tube walls and thereby substantially reduce the risk of distortion damage to both the compression tube and the piston. In diaphragm-bursting apparatus, the potential for damage by overpressurization exists, where a failure of the diaphragm to burst causes the gas pressure on the face of the piston to continue to build up until the piston rebounds. Engagement of the brakes under such circumstances results in excessive forces being applied to the compression tube walls and the piston.

The fundamental geometry and mechanics of the preferred wedge brakes mean that the wall pressure exerted by the brakes to produce the friction force is proportional to the piston's rearward acceleration and hence approximately to the frontal pressure on the piston.

For designs of wedge brakes as described above and for pistons of reasonable length, it is desirable to employ a piston-brake geometry such that the tube wall pressure generated by the brakes in order to produce the required friction, exceeds the frontal pressure on the piston. The presence of the brakes therefore means that the tube wall pressure may exceed the maximum gas pressure for which the tube would otherwise be designed, and under such circumstances the force of application of the brakes is desirably limited to minimize tube damage.

The force limiting means may take any suitable form. For example, a wedge brake as described above may be employed, modified by the addition of a pliable layer of material between the backing of the shoes and the friction material. This material may be applied in a conformation which will allow of substantial compression deformation of the material in the radial direction before reaching the limit of compression. For example, the friction material and backing may be provided with a resilient layer having circumferential grooves or other voids to accommodate compressive deformation.

The effect of this modification is that under violent backwards acceleration of the piston, the pliable material can collapse, so that the normal force which can be applied to the wall of the tube is limited to a maximum which is related to the properties of the pliable material layer and the constraint placed on the motion of the brake shoe within the tapered portion of the piston body. The frictional force will therefore also be limited allowing the brakes to slip when the piston motion reverses.

Alternatively, force limitation may be achieved by provision of wedge brake shoes in which the friction material is chosen to fail in compression at a pressure below the maximum design limit so as to limit the pressure which can be developed. The friction material may, in addition or in the alternative, be chosen so as to fail in shear at a friction force which corresponds to a pressure below the maximum wall pressure limit.

In a yet further means of limiting forces, a wedge brake design is utilized having a stop ring included on the piston to limit the travel of the shoes up the taper. The shoes themselves may be designed as to thickness and stiffness such that the pressure generated on the wall just reaches the maximum acceptable value as the shoes reach the stop ring. As the brake shoes wear, the limiting value of wall pressure will decrease, providing this embodiment with inherent safety from the point of view of tube protection.

Moreover, a combination of force limiting features may be appropriate. For example, a combination of sacrificial shoes and limit stops may provide an additional margin of safety. The use of sacrificial shoes relies upon the material failing either in shear or in compression in such a way as to limit or reduce the wall pressure. This assumes that once the material has failed, it cannot once again build up load, even if the shoe continues to move up the wedges. To allow for materials which may build up load after failure, the addition of motion stops as described above may provide an ultimate safety limit.

Alternatively, the brake wedges may take a form having the friction material shaped with a conical inner surface and with the shoe backing material having a taper on the outside as well as the inside, the two tapers being in opposite directions, and with the friction material wedge bonded to the backing wedge with a bonding agent of limited shear strength. In action, if the friction force is such as to exceed the design limit, the bond line will fail and the friction wedge will be released from the backing wedge by an unlocking action opposite to the locking action of the brakes.

As hereinbefore described, it has been a practice to provide piston control against primary impacts only, by controlling the parameters of gas filling pressures for the propellant and driver gases, and diaphragm burst pressure if applicable. However, the accuracy with which these can be determined and the energy of the piston mean that injurious collisions have proved to be unavoidable.

Accordingly, in a further aspect, this invention resides broadly in a free piston driver apparatus including:-

a compression tube;

a free piston drivable within said compression tube and adapted to compress a driver gas at an end of said compression tube;

holding means adapted to prevent said piston from rebounding off said compressed driver gas, and

buffer means adapted to resist said piston colliding with said end.

The buffer means may take any form consistent with the function of resisting the piston colliding with the end of the compression tube, and may be operatively associated with the tube, the piston or both. For example, the buffer means may take the form of a gas trapping buffer which functions by trapping a portion of the driver gas in a chamber whereupon the portion of gas is compressed by the advancing piston and in so compressing buffers the piston from hitting the compression tube end.

The gas trapping buffer may take the form of an annular projection from the face of the piston, said annular projection being adapted to pass into a corresponding annular recess provided in the region of the downstream end of the compression tube. Gas in the recess may be compressed within the annular recess by the advancing annular projection. Of course, the arrangement may be reversed such that the recess is provided in the piston face.

If desired, the gas trapping buffer may be provided with dashpot-like characteristics to limit the rebounding forces applied to the piston at the end of the compression stroke of the piston. For example, the compressed buffer gas may bleed at a selected rate from passages provided in the buffer means. Preferably, there is provided a series of apertures which may be successively occluded as the front of the piston moves forward, thus controlling the area available for gas escape and hence the rate of escape. Alternatively, the buffer gas may be bled by the provision of a selected clearance of the annular gap between the piston and the cylindrical wall.

Further modification of buffer behaviour may include provision of a spring loaded annular valve ring or such like which occludes the bleed holes. Preferably, the configuration of the valve is such that arrival of the piston results in the valve being forced off the bleed holes, allowing the gas to vent from the chamber. Some high pressure gas may be trapped ahead of the valve ring, such that when the pressure between the piston and the valve ring falls, the trapped gas assists the spring to return the valve and seal the bleed holes. As the piston rebounds, the pressure in the now sealed buffer recess will rapidly fall to a value below that behind the piston. The piston will therefore cease backward motion and remain trapped.

Preferably, means are provided allowing the trapped gas pressure to escape slowly through apertures having a small cross-sectional area, the apertures extending through the valve ring and co-operating with corresponding apertures provided through the portion of the cylindrical wall not normally occluded by the valve ring. This results in a moderated equalization of the pressures in the apparatus at rest, with no significant pockets of either high pressure gas or partial vacuum remaining.

As an alternative to the use of gas buffers as described above, there may be provided an inertia controlled piston valve internally to the piston which has the ability to vent high frontal pressure on the piston to the rear when opened. Preferably, the valve seats on a conical surface in the front of the piston and is attached to a substantial mass of material on the interior of the piston. The valve may be free to move axially within the piston between limits, or may be biased as appropriate.

In use, the valve is preferably closed by propellant gas pressure at the rear of the piston during the acceleration phase of piston travel. As pressure on the front of the piston exceeds pressure behind, the valve has a tendency to open and relieve that pressure. However, the ratio of the masses of the valve and the remainder of the piston body and the ratio of the frontal areas of the valve and the remainder of the piston body, are preferably selected such that the retarding force on the piston body causes a deceleration which exceeds that of the valve, so that while forward piston motion continues under deceleration, the valve will remain closed.

Once the piston has been brought to rest and reverses, the inertial imbalance no longer applies and the valve opens, relieving the frontal pressure and thus removing the tendency for the piston to rebound. The exact balance of forces on the valve may be adjusted by adding a spring which tends to close the valve.

In a yet further embodiment, the buffer means comprises a combination of the aforedescribed gas buffer with an annular impact buffer of resilient material. Preferably, the annular impact buffer is selected such that the deceleration of the piston after contact with the buffer rises in a selected manner. For example, the resilient impact buffer may be provided with a tapered cross section such that as the narrow, first-contacted region is compressed to its limit, the resisting force progressively increases as portions adjacent thereto compress.

-- DESCRIPTION OF THE PREFERRED EMBODIMENT --

In order that this invention may be more easily understood and put into practical effect, reference will now be made to the accompanying drawings which illustrate a preferred embodiment of the invention, wherein:-

FIGS. 1 and 2 are schematic cross sections illustrating the mode of operation of apparatus in accordance with the present invention;

FIG. 3 is a detail schematic cross section through alternate apparatus to that of FIGS. 1 and 2;

FIGS. 4 to 6 are cross sections through brake shoe configurations suitable for use in conjunction with apparatus in accordance with the present invention;

FIG. 7 is a schematic cross section through a valved piston buffer arrangement in accordance with the present invention;

FIGS. 8 to 11 represent alternative gas buffers in accordance with the present invention.

In the FIGS 1 and 2 there is illustrated a cross section through a compression tube 10 having a free piston 11 drivably mounted therein. A brake is built into the outer body of the piston 11. The brake comprises a tapered portion 12 of the piston 11, machined to give a tapered or conical surface, with the smaller diameter to the rear of the piston. Brake shoe segments 13 with a matching taper to the tapered portion 12 are arranged within the conical space defined by the conical portion 12 and the wall of the tube 10.

In use, during forward motion and forward acceleration of the piston 11, the brake shoe segments 13 tend to move towards the smaller diameter region of the tapered portion 12 where they are clear of the tube wall. During forward motion but negative acceleration of the piston 11, the brake shoe segments 13 would move towards the larger diameter end of the tapered portion 12. However, any contact with the walls of the tube 10 would tend to produce a relatively rearward motion of the brake shoe segments and hence no significant braking force is applied.

When the piston 11 reverses direction, for example, when rebounding off a driver gas, the brake shoe segments 13 move up the tapered portion 12 and make contact with the wall of the tube 10. This produces a friction force which tends to carry the brake shoe segments 13 further up the tapered portion 12 and hence increase the normal contact force with the wall of the tube 10, and hence the braking force between the piston 11 and the tube 10.

Limitation by braking of the distance which the piston 11 can rebound back along the tube 10 reduces the scope for subsequent forward acceleration when the gas pressure in front of the piston 11 has reduced. This in turn will limit the possible forward velocity of the piston 11 when it finally moves forward and reaches the end of the compression tube 10.

In addition, reduction of rearward motion of the piston 11 means that the pressure in front of the piston 11, which has been built up during the compression stroke, is maintained at a higher level than would be the case if the piston 11 rebounded, thus increasing the useful pressure in the gas available to do work in the driven device.

In the embodiment of FIG 3., there is provided a brake shoe segment 13 as before adapted to move along the tapered portion 12 to apply a braking force between the piston 11 and the tube 10. A stop ring 14 is formed integrally with the piston 11 to limit the aforesaid braking force. As the brake shoe segments 13 wear, the limiting value of wall pressure will decrease, providing this embodiment with the advantage of inherent safety from the point of view of protection of the tube 10.

In FIGS. 4 to 6, there is illustrated a variety of brake shoe segments of a type suitable for use in conjunction with the present invention. The brake shoe segments generally include a backing portion 15 having a low friction surface 16 coated with polytetrafluorethylene and adapted to conform with and slide over the surface of the tapered portion 12 of the piston 11. The backing portion 15 is in this embodiment selected of a soft grade of aluminium which is flexible relative to the piston 11 so as to allow deformation of the shoes to match the varying diameter of the tapered portion 12 when the brake shoe segment moves axially relative to the piston 11.

A layer of a friction material 17, in this case a metal impregnated resin brake material, is bonded to the outer surface of the backing portion 15, the bond being of high shear resisting characteristic to prevent delamination under braking loads.

The brake shoe segments are held in place around the tapered portion 12 of the piston 11 by a resilient restraint comprising a neoprene O-ring 20 positioned in a groove 21 provided in the friction material 17. The restraint is particularly useful when the piston 11 is removed from the tube 10 and alleviate unnecessary wear of the tube 10 and brake shoe segments 13 during compression by the piston 11.

In the embodiment of FIG. 4, the friction material 17 and backing portion 15 are each shaped to have conical mating surfaces 22, the respective inner and outer tapers of the backing portion being in opposite directions. The friction material 17 is bonded to the backing portion 15 with a bonding agent of high but limited shear strength. In use, if the frictional force is such as to exceed a preselected limit, the bond line fails and the friction material 17 will be released from the backing portion by an unlocking action opposite in action to the locking action of the brake shoe segments.

In the embodiment of FIG. 5, there is illustrated a brake shoe segment 13 of increased shear strength, the increase in shear strength being afforded by mating serrated surfaces 23 provided on each of the backing portion 15 and the friction material 17.

In the embodiment of FIG. 6, the backing portion 15 and the frictional material 17 are separated by a layer 24 of a polyester thermoplastic elastomer of suitable properties, allowing of substantial deformation of the layer 24 in the radial direction without forming a solid mass between the backing portion 15 and the friction material 17. The layer 24 is provided with circumferential grooves 25 to accommodate compression of the layer 24.

In use, under violent rearward acceleration of the piston 11, the compressible layer 24 may collapse, so limiting the normal force which can be applied to the wall of the tube 10 to a maximum which is related to the properties of the layer 24 and the constraint placed on the motion of the brake shoe segment 13 within the tapered portion 12 of the piston 11. The frictional force will therefore also be limited and the brake shoe segments may slip when the piston motion reverses.

In the embodiment illustrated in FIG. 7, the piston 11 is provided with a valve housing portion 26 defining the front face of the piston 11. The valve body portion 26 is provided with an axial bore 27 adapted to house a relatively massive valve closure body 30. The valve closure body 30 is adapted to slide axially within the bore 27 and seats on a conical sealing surface 31. The conical sealing surface is perforated by an opening 32 to the front of the piston 11, the opening providing fluid communication between the downstream side of the piston 11 and the bore 27.

The opening 32 is closed by pressure in the compression tube 10 acting at the rear of the valve closure body 30 which exceeds frontal pressure during the acceleration phase of piston travel. As pressure on the front of the piston 11 exceeds pressure behind, the valve closure body 30 has a tendency to open the opening 32 and relieve that pressure. However, the ratio of the masses of the valve closure body and the remainder of the piston 11 and the ratio of the frontal areas of the valve closure body 30 and the remainder of the piston 11, are so arranged that the retarding force on the piston 11 causes a deceleration of the whole which exceeds that of the valve closure body 30, so that while forward piston motion continues combined with retarding acceleration, the opening 32 will remain closed. Once the piston 11 has been brought to rest and reverses, the inertial imbalance no longer applies and the opening 32 opens, relieving the frontal pressure and thus removing the tendency for the piston 11 to rebound. The exact balance of forces on the valve closure body 30 can be adjusted by adding a spring which tends to close the valve.

In the embodiment illustrated in FIG. 8, there is illustrated apparatus of the free piston kind adapted for bursting of a diaphragm 39, wherein collision of the piston 11 with the end of the compression tube 10 is substantially alleviated by provision of an annular chamber 33 defined by an annular collar 34, the end 35 of the tube 10 and the wall of the tube 10. The face of the piston 11 is provided with an annular protrusion 36 adapted to closely fit within the annular chamber 33 to close the open face thereof.

In use, impact of the piston 11 on the end 35 of the tube 10 may be prevented by trapping a portion of the driver gas in the chamber 33 to form a gas buffer. Upon arrival of the piston 11, the piston protrusion 36 substantially seals the annular chamber 33. As the piston 11 proceeds forwards the gas trapped in the chamber 33 is compressed and decelerates the piston 11, thereby preventing contact with the end 35 of the tube 10.

In the embodiment illustrated in FIG. 9, there is provided a gas trapping buffer substantially as per that of FIG. 8, but further including a series of bleed passages 37, 38 adapted to allow some escape of the trapped driver gas from the chamber 33 to the downstream side. Buffer gas bleeding may reduce the tendency for the piston 11 to rebound off the compressed gas trapped in the chamber 33. The bleed passages 37, 38 are in use successively occluded by the annular protrusion 36 as the front of the piston 11 moves forward, thus controlling the area available for gas escape and hence providing progressive buffering of the piston 11.

Where a fixed rate of buffer gas escape is required, this may be provided by allowing a selected clearance in the annular gap 40 between the piston protrusion 36 and the outer wall of the annular collar 34.

In the embodiment illustrated in FIG. 10, the closure of the bleed passages 37, 38 is effected by addition of a spring loaded valve comprising an annular valve ring 41 biased over the bleed passages 37, 38 by the action of springs 42. When the piston 11 arrives, generating high pressure, the valve ring 41 is forced forward by the pressure, opening the bleed passages 37, 38 progressively and allowing the gas to vent from the chamber 33. Some high pressure gas is however trapped ahead of the valve ring 41 to provide a buffer. When the pressure between the piston 11 and the valve ring 41 falls, the trapped gas assists the spring 42 to return the valve ring 42 and seal the bleed passages 37, 38. The chamber portion 43 defined by the annular collar 34, the front of the piston protrusion 36 and the valve ring 41 is now effectively sealed. As the piston 11 rebounds, the pressure in the sealed chamber portion 43 will rapidly fall to a value below that behind the piston 11. The piston 11 will therefore cease backward motion and remain trapped.

Any trapped gas pressure is permitted to slowly bleed out to equilibrium by the provision of small diameter holes (not shown) through the valve ring 41 and through the portion of the annular collar 34 not normally occluded by the valve ring 41. This ensures that at the end of a particular free piston event, within a reasonable time no pockets of either high pressure gas or partial vacuum remain.

In the embodiment illustrated in FIG. 11, there is illustrated a gas trapping buffer substantially as per the embodiment of FIG. 8, wherein the buffer characteristics are modified by the provision of a progressively acting annular elastomeric buffer 44 located in the chamber 33. The elastomeric buffer 44 in use contacts the advancing face of the piston projection 36 and commences to progressively decelerate the piston 11. As the deceleration increases, the piston protrusion 36 seals the chamber 33 as before, resulting in a further increased rate of deceleration, the pressure on the walls of the elastomeric buffer 44 also tending to counter the crushing of the buffer 44.

It will of course be realised that while the above has been given by way of illustrative example of this invention, all such and other modifications and variations thereto as would be apparent to persons skilled in the art are deemed to fall within the broad scope and ambit of this invention as claimed in the following claims.

-- CLAIMS --

1. Free piston driver apparatus including:-

a compression tube having a driving end and a compression end;

a free piston drivable within said compression tube towards said compression end and adapted to compress a driver gas at an end of said compression tube;

driving means associated with said driving end, and

holding means for restraining said piston from rebounding from said compression end.

2. Free piston driver apparatus as claimed in claim 1, wherein said holding means includes brake means associated with the piston and engageable with the compression tube.

3. Free piston driver apparatus as claimed in claim 2, wherein said brake means includes a plurality of tapered shoe segments normally spaced from the compression tube inner wall and operable to engage the compression tube inner wall.

4. Free piston driver apparatus as claimed in claim 3, wherein said plurality of tapered shoe segments are supported about a conical outer surface of said free piston whereby advancement of said segments along said piston causes said segments to move into engagement with said compression tube inner wall.

5. Free piston driver apparatus as claimed in any one of the preceding claims, wherein said holding means is held in place around the piston body by a resilient restraint whereby said holding means may be removed from and/or inserted into the compression tube.

6. Free piston driver apparatus as claimed in any one of the preceding claims, wherein said holding means includes operable brake means.

7. Free piston driver apparatus as claimed in any one of the preceding claims and including force limiting means for limiting the force of said holding means on the compression tube walls.

8. Free piston driver apparatus as claimed in claim 7, wherein said force limiting means limits force sufficiently to substantially reduce distortion to the compression tube and/or the piston.

9. Free piston driver apparatus as claimed in any one of the preceding claims and including collision buffer means operatively interposed between said piston and said compression end.

10. Free piston driver apparatus as claimed in claim 9, wherein said buffer means includes a gas compression chamber.

11. Free piston driver apparatus as claimed in claim 10, wherein said gas compression chamber is provided with at least one bleed passage.

12. Free piston driver apparatus as claimed in claim 10 or claim 11, wherein said gas compression chamber is an annular chamber formed between the piston and said compression end.

13. Free piston driver apparatus as claimed in claim 11 or claim 12, wherein said bleed means includes the clearance of the annular gap between the piston and the cylinder wall.

14. Free piston driver apparatus as claimed in claim 9, wherein said buffer means includes an inertia controlled piston valve internal to the piston, said piston valve being able to vent higher frontal pressure on the piston to the rear of the piston when opened.

15. Free piston driver apparatus as claimed in claim 14, wherein said piston valve is operatively associated with a substantial mass of material on the interior of the piston.

16. Free piston driver apparatus as substantially hereinbefore described in reference to the accompanying drawings.

[1/4]

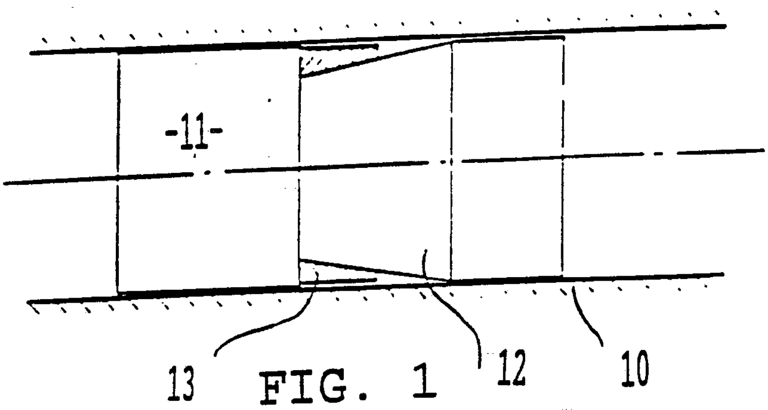

FIG. 1

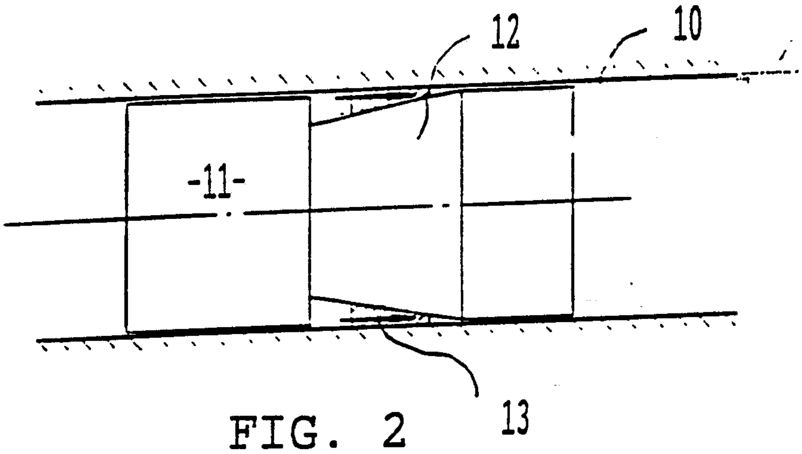

FIG. 2

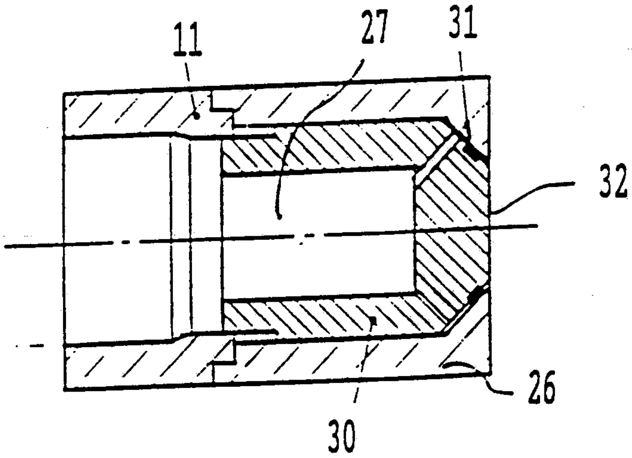

FIG. 7

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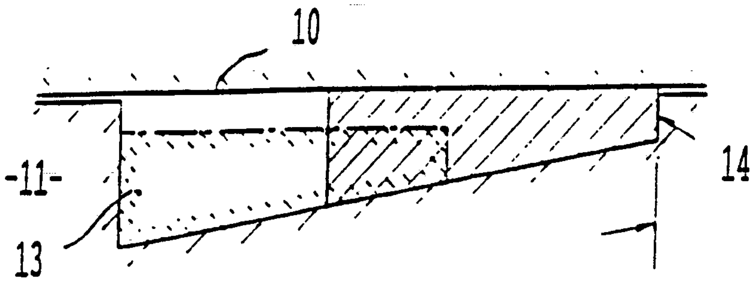

FIG. 3

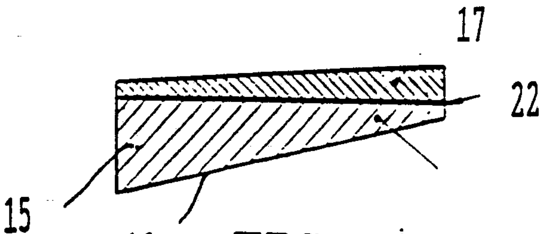

FIG. 4

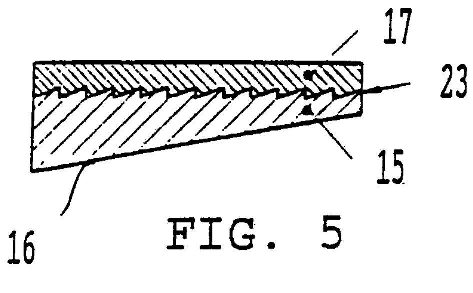

FIG. 5

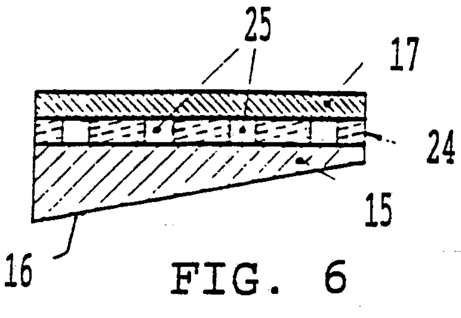

FIG. 6

[3/4]

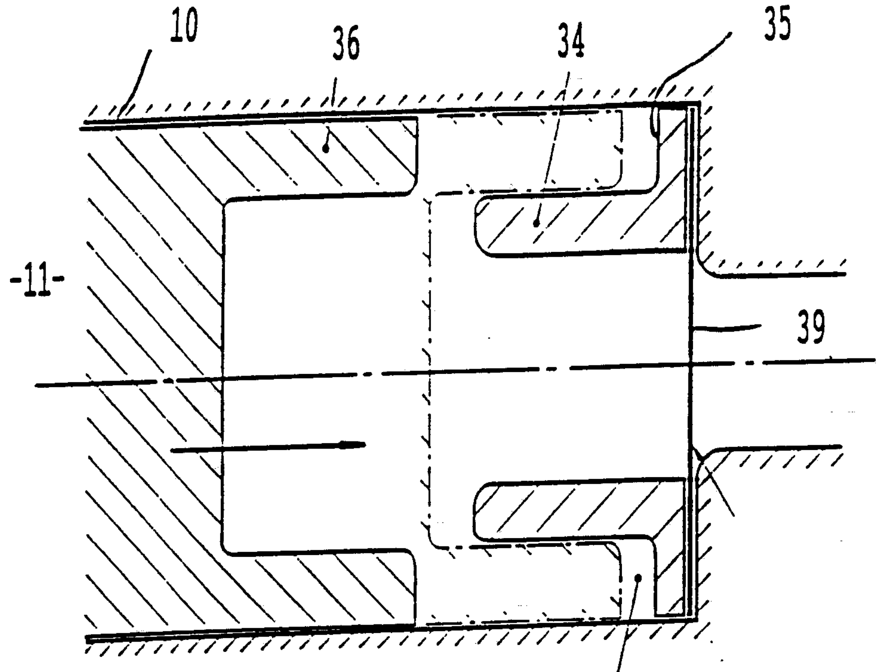

FIG. 8

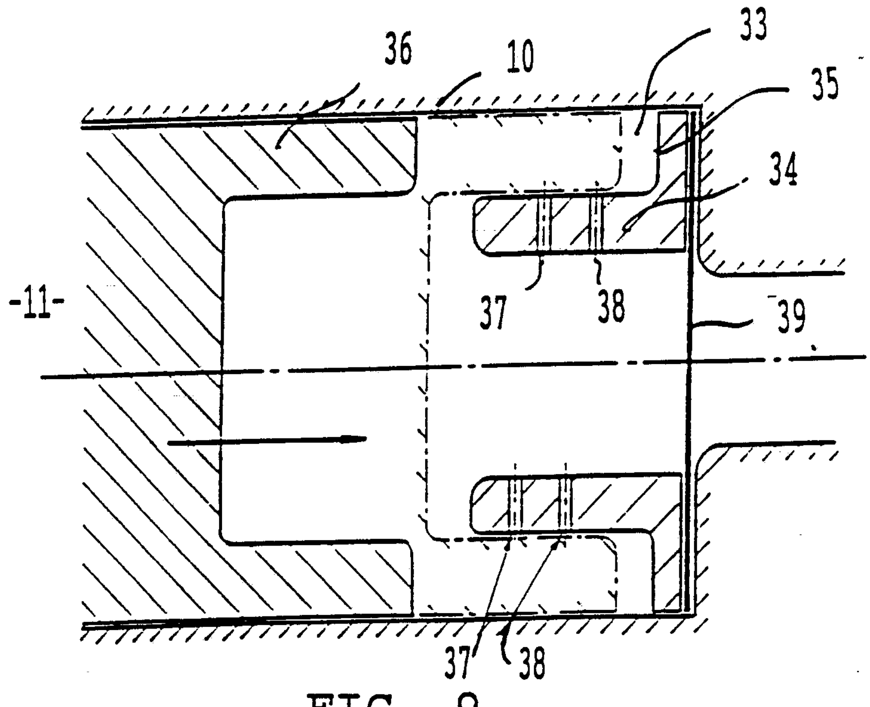

FIG. 9

[4/4]

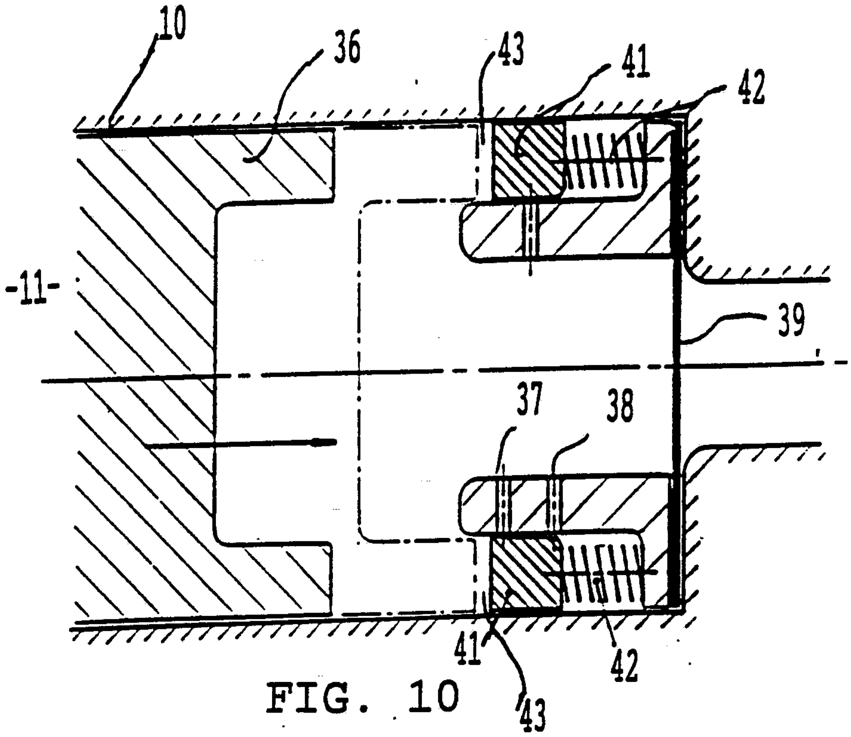

FIG. 10

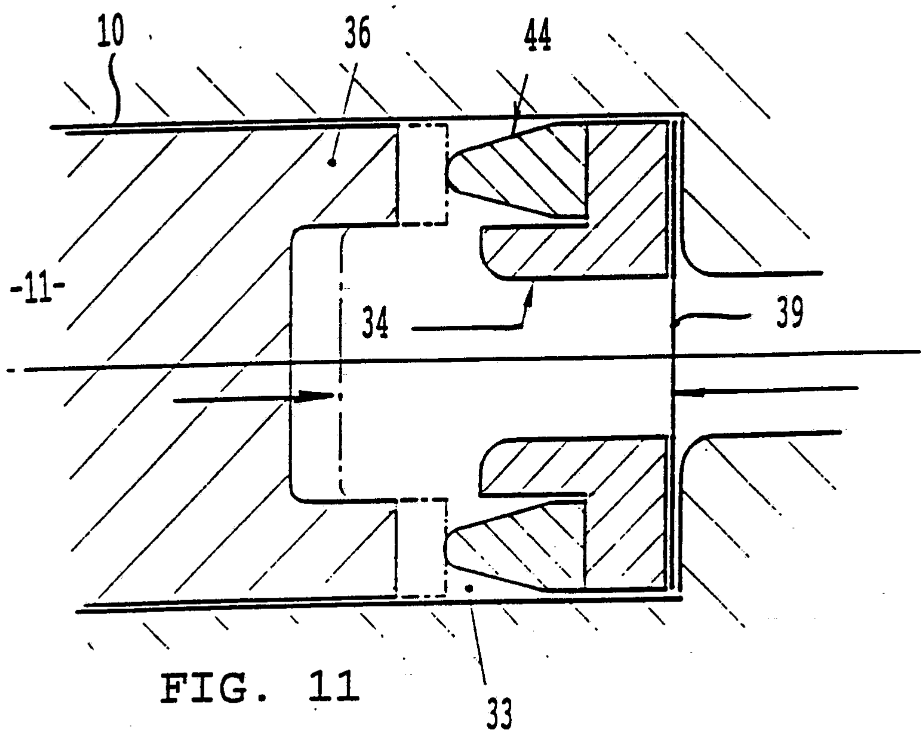

FIG. 11

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.[5] F01B 11/02, F02B 71/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC F01B 11/02, F02B 71/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC as above; Australian Classification 65.3, 66.2

Electronic data base consulted during the international search (name of data base, and where practicable, search terms used)
DERWENT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate of the relevant passages	Relevant to Claim No.
	GB,A,1285952 (BRAUN) 16 August 1972 (16.08.72)	
X	page 2, line 129 - page 7, line 69	1, 9-10, 13
Y	page 2, line 129 - page 7, line 69	11
	US,A,2434277 (LEWIS) 13 January 1948 (13.01.48)	
Y	column 1, line 45 - column 3, line 22	1-2, 11
	AU,B,50942/85 (581044) (BRAUN) 23 April 1987 (23.04.87)	
X	page 8, line 23 - page 11, line 15	1

[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 September 1992 (11.09.92)	24 Sept 1992 (24.09.92)
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200 WODEN ACT 2606 AUSTRALIA Facsimile No. (06) 2853929	Authorized officer C. M. Wyatt Telephone No. (06) 2832538

C(Continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	
Category*	Citation of document, with indication, where appropriate of the relevant passages	Relevant to Claim No.
X	AU,A,79141/87 (BRAUN) 12 January 1989 (12.01.89) page 4, line 14 - page 8,line 5	1
Y	US,A,3678808 (HSU et al) 25 July 1972 (25.07.72) column 1, line 59 - column 3, line 35	1
Y	AU,B,36985/58 (222075) (OLIN MATHIESON CHEMICAL CORPORATION) 16 October 1958 (16.10.58) column 5, line 10 - column 6, line 25	1
Y	AU,B,17575/67 (283706) (SIDDONS) 20 April 1967 (20.04.67) page 3, line 32 - page 7, line 5	1-2

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
GB	1285952	CH	549153	DE	1937053	FR	2013491
		IE	33649	IL	32670	JP	49035643
		NL	6911203	SE	351264	US	3501088
		ZA	6905189				
AU	50942/85	AT	68037	BR	8507298	DK	2941/87
		WO	8702423	DE	3584293	EP	246227
		JP	63502523	NO	872410		
AU	79141/87	AT	75528	WO	8900245	DE	3778710
		EP	340214				

END OF ANNEX