

[54] **MEANS AND METHOD FOR PREVENTION OF PISTON CREEP IN FREE-PISTON RECIPROCATING DEVICE**

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[51] Int. Cl. **F02g 1/04**

[58] Field of Search 92/86.5, 86, 127, 162, 92/181, 172; 60/518, 520

[56] **References Cited**

UNITED STATES PATENTS

2,833,602 5/1958 Bayer..... 92/127

3,319,534 5/1967 Boonshaft..... 92/162

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[57] **ABSTRACT**

A free-piston motion device is provided having means associated with either the cylindrical surface of the free-piston or with its co-acting cylinder or both to maintain the mid-point of the stroke of the piston in a predetermined relation to its cylinder during reciprocation of the piston.

9 Claims, 7 Drawing Figures

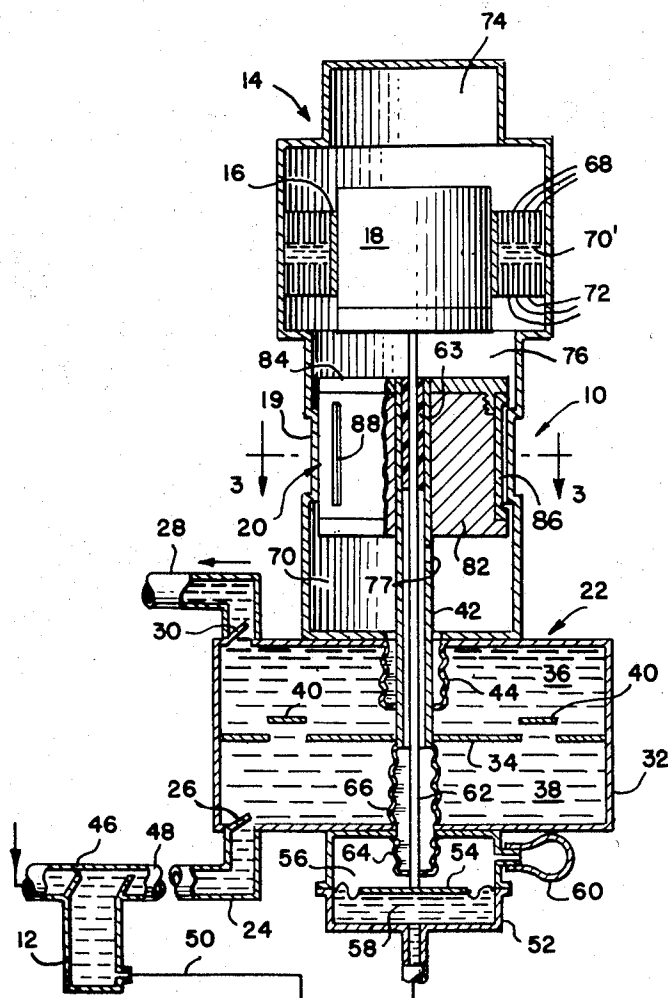


FIG. 1.

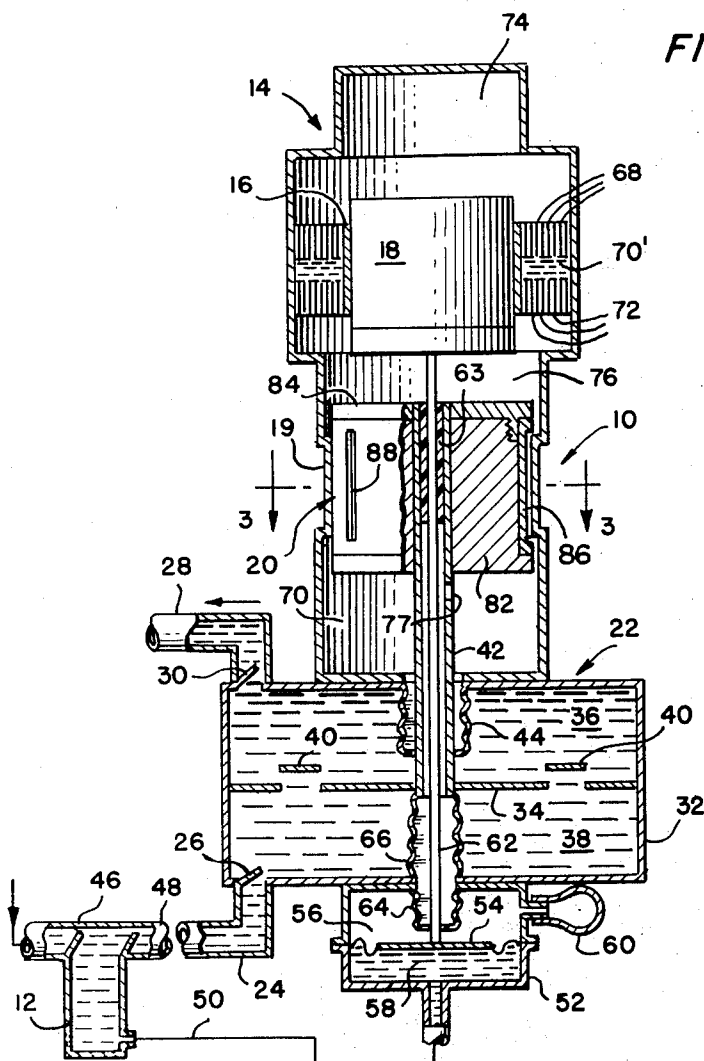


FIG. 2.

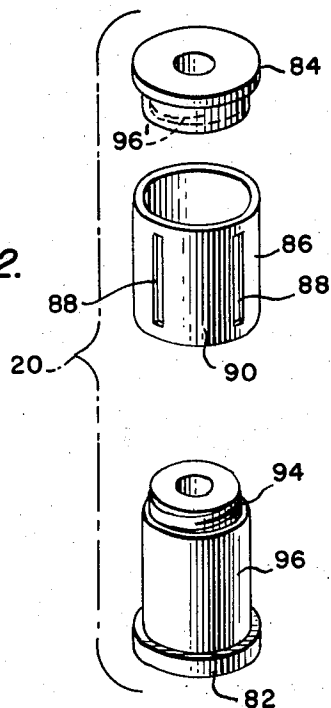


FIG. 3.

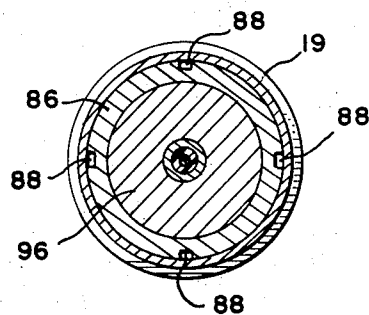


FIG. 4.

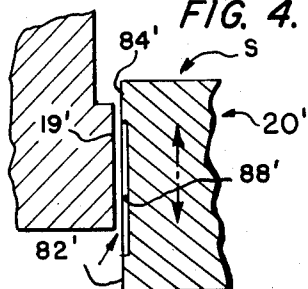


FIG. 5.

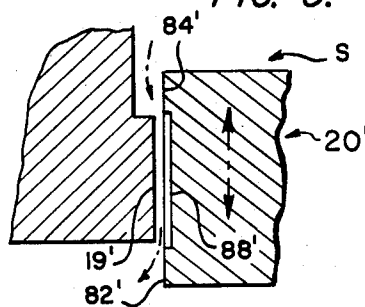


FIG. 6.

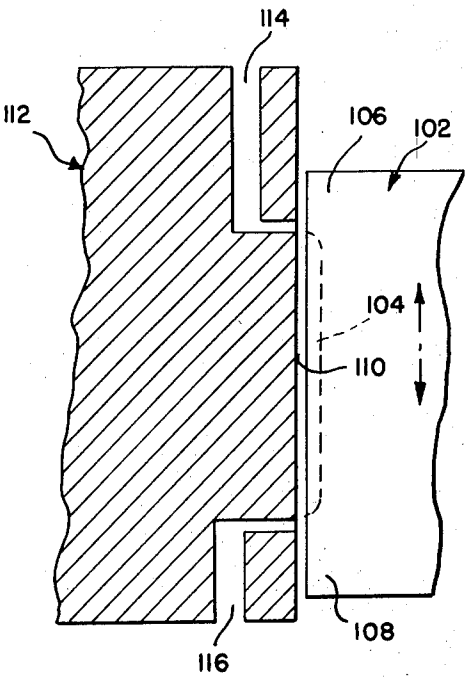
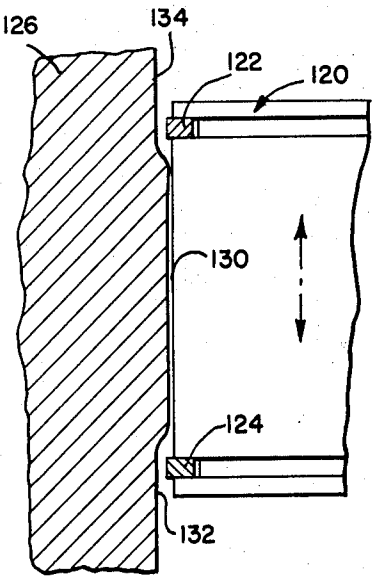


FIG. 7.



MEANS AND METHOD FOR PREVENTION OF PISTON CREEP IN FREE-PISTON RECIPROCATING DEVICE

Related subject matter is disclosed and claimed in my U.S. Pat. No. 3,552,120 issued Jan. 5, 1971 and 3,645,649 issued Feb. 29, 1972.

Free-piston Stirling cycle thermal engines or refrigerating devices wherein there are no mechanical connections between the pistons and displacer for maintaining the proper phase relationship between these parts are known in the art. In such Stirling cycle devices and other closed-cycle free-piston engines and motion devices such as gas and spring biased shock absorbing means, the gaseous fluid has a tendency to leak past the pistons resulting in a tendency for the pistons to slowly creep in or out of their normal cyclic path of reciprocation, thereby lowering efficiency of the engines, refrigerators or devices and eventually rendering them inoperative for their intended use.

It is a primary object of the present invention to provide automatic means for overcoming the inherent piston creep in free-piston motion devices.

Further objects are to provide means and methods for overcoming piston creep in free-piston motion devices that do not materially add to the cost of construction of the devices; nor materially reduce the operating life or otherwise reduce the utility or efficiency of such devices.

These and other objects and advantages are provided in a free-piston Stirling cycle engine or pump having at least one free-piston mounted for reciprocation in a cylinder, a pressurized gaseous fluid maintained in the cylinder at at least one end of the free-piston the improvement comprising means associated with the cylindrical walls of the piston and the cylinder for reducing the tendency of the piston to creep into or out of the working gas space of the cylinder as it reciprocates in the cylinder, wherein the cylinder has a snug piston receiving bore and means on the cylinder or piston or both providing at least one gas passage of a length less than the length of the piston and extending in opposite directions from the mid-point of the stroke of the piston; and by a method of reducing the tendency of a free-piston of a free-piston motion device to creep into or out of the working space of its cooperating cylinder comprising the steps:

forming a bore in a cylinder to snugly receive a piston within the bore; and

forming an axial gas passage in the cylindrical surface of the piston, the cylinder, or both of a length less than the length of the piston.

Throughout the specification and claims, the term — free-piston motion device — means an engine, pump, shock absorber or other mechanical arrangement of mechanism including at least a piston having no mechanical linkage connected thereto which linkage would provide for maintaining the reciprocation of the piston in some predetermined cyclic relation to the cylinder space within which the piston reciprocates; and the term — cylinder working space — means that length of the cylinder bore which is traversed by the reciprocating piston when the piston is reciprocating on its designed and optimum path.

The invention will be more particularly described in reference to a free-piston Stirling cycle-type thermal

device and in conjunction with the accompanying drawing wherein:

FIG. 1 is a partial sectional view of a Stirling cycle-type servo pump constructed in accordance with the teaching of the invention;

FIG. 2 is an exploded perspective view of the power piston of the engine shown in FIG. 1;

FIG. 3 is a section on line 3—3 of FIG. 1;

FIGS. 4 and 5 are diagrammatic sketches showing gas sealed and unsealed positions of a piston and cooperating cylinder; and

FIGS. 6 and 7 show modified forms of the present invention.

Referring to the drawings and in particular FIGS. 1 through 3, 10 generally denotes a Stirling cycle type servo pump generally of the type disclosed and claimed in my U.S. Pat. No. 3,645,649 issued Feb. 29, 1972.

The servo pump 10 includes a housing 14 which defines a cylinder 16 in which a displacer piston 18 is mounted for reciprocation.

A power piston 20 is reciprocally mounted in the housing 14 in a cylinder portion 19 beneath the displacer piston 18 and drives a pump 22. The pump is provided with an inlet 24 controlled by an inwardly opening flapper valve 26 and an outlet 28 controlled by an outwardly opening flapper valve 30.

The pump 22 comprises a housing 32 having a pump piston 34 reciprocally mounted therein to divide the housing into an upper chamber 36, communicative with the outlet 28 and a lower chamber 38 communicative with the inlet 24. Communication between the chambers is provided by check valves, shown schematically at 40, through the piston 34. The power piston 20 drives the pump piston 34 through a hollow drive shaft 42 which traverses communicating openings in adjacent portions of the housing 14 and pump housing 32. A bellows seal 44 is disposed between the shaft 42 and the openings in the housings to provide a seal between housings.

The heart, the left ventricle of which is schematically shown at 12, communicates through a valved return, with the left auricle at 46 and through the aorta 48 is connected to the pump inlet 24. A branch duct 50 also connects the heart to a diaphragm chamber 52 disposed beneath the pump 22. The chamber 52 is provided with a diaphragm 54 which divides that chamber into upper and lower sections 56 and 58, respectively. A flexible bag 60 communicates with the upper section 56 for purposes to be described in greater detail below.

The diaphragm 54 is connected to the displacer piston 18 by means of a drive rod 62 which traverses the pump 22 coaxially through the hollow drive shaft 42 and power piston 20. A bellows seal 64 between the lower end of the shaft 62 and the diaphragm chamber isolates the upper section 56 of that chamber from the lower chamber 38 of the pump 22. A bellows seal 66, around the rod 62 between the lower wall of the pump 22 and the piston 34, isolates the lower chamber 38 from the interior of the hollow drive shaft 42.

The displacer rod 62 runs through a close sliding seal 63 serving to separate the space 76 and its varying pressure from the bounce space 70 which is relatively large and has approximately constant pressure, of, for example, 2,000 p.s.i.

The remainder of the hollow drive rod space including the space within the bellows seals 44, 66, 64, is held

at bounce space pressure by means of a hole 77 in the drive rod between the bounce space and the interior of the drive rod. Since the difference in area of the upper and lower surfaces of the piston 18 is only the area of the displacer piston rod pressure of the gas in space 76 does not serve to drive the displacer appreciably. The displacer is then free to be driven only by the blood pressure acting on diaphragm 54,

The upper end of the housing is provided with heaters, regenerators and coolers, schematically shown at 68, 70' and 72, respectively, in the bypass path around the displacer piston 18. The construction, function and operation of this portion of the thermal device is more fully set forth in the hereinbefore referred to U.S. Pat. No. 3,552,120, particularly in the description of FIG. 6 thereof. For the purposes of this disclosure, it suffices to say that the devices 68, 70' and 72 function, when connected to suitable sources of energy, to cool gas being circulated downwardly therethrough by upward movement of the displacer piston 18 and to heat gas being circulated upwardly therethrough by downward movement of the displacer piston thereby providing a hot zone 74 in the housing above the piston 18 and a cold zone 76 below the piston.

The housing is charged with a gas at high pressure, such, for example, as with helium or hydrogen gas at 2,000 p.s.i. For this reason the housing 14 is fabricated to withstand high internal pressures.

In order to provide a substantially neutral system, e.g., one in which there are no large biasing forces acting on the pistons, spring effects are built into one or more of the bellows seals 44, 64 and 66 to balance the charge gas pressures on the moving parts so that they may move readily under the influence of fluid pressure changes.

The upper section 56 of the diaphragm chamber 52 is charged with air or inert gas at ambient pressure. The bag 60 serves to equalize the pressure within the upper section with barometric changes of pressure in the ambient zone.

With the device charged as above, the inlet 24 is connected to the aorta 48, the outlet 28 to the inlet to the arterial system and the pump chambers 36 and 38 and connecting lines are flooded with blood. The branch duct 50 is connected to the heart 12 and the lower section 58 of the diaphragm chamber is filled with blood so that pressure pulses from the heart can be transmitted to the diaphragm 54. The heater 68 and cooler 72 are then energized and the servo pump 10 operates as set forth in greater detail in my said U.S. Pat. No. 3,645,649.

It will be noted that the Stirling cycle engine which drives the servo-pump is of the free-piston type, that is, both power piston rod 42 and displacer piston rod 62 are free of any linkage, gearing or other mechanical connection or interconnection which would either limit the excursion of either of the pistons or establish a phase relationship in the motions of power piston 20 and displacer piston 18. Without some form of mechanical restraint it has been found that the power piston 20 has a tendency to slowly creep either in or out of the working gas space 76 as the power piston 20 cycles. This tendency of the power piston to creep has been found to be caused by the tendency of the working fluid to leak into or out of the working gas space 76. If the leak tendency is from space 76 then piston 20 would slowly creep into the space 76. However if the

tendency is for the working fluid, in this case helium or hydrogen gas at, for example, 2,000 p.s.i., to leak into the working gas space 76 then the piston 20 will have a corresponding tendency to creep out of the space 76. Control of gas leakage into and out of the working space 76 can be had by providing the power piston 20 with a pair of end seals separated by a zone having one or more controlled leakage passages. Referring again to the drawing and in particular FIGS. 1 through 3, the piston 20 comprises ends 82 and 84 and a sleeve 86 which sleeve is formed with a number, four being shown, of longitudinal grooves 88 milled in a portion of the outer cylindrical surface 90 thereof. Ends 82 and 84 are sized to provide a snug, close sliding fit in the cylinder 19 and the milled grooves 88 on the sleeve 86 to provide a relatively leaky section. In the illustrated form of the invention the sleeve 86 is maintained on the piston by external threads 94 on the center portion 96 and internal threads 96' on the end cap 84. It will be appreciated, however, that piston 20 may be made as a unitary piece by merely milling grooves on a portion of the external cylindrical surface thereof.

As hereinbefore set forth positive size relationships exist between the length of the piston 20, and the length and position of the milled grooves on the piston.

The functioning of the hereinbefore described mechanism will best be understood in reference to FIGS. 4 and 5 of the drawings wherein 20' designates a portion of a power piston similar to that of FIGS. 1 through 3 and 19' designates a portion of a cylinder similar to cylinder 19 with the other primed reference characters designating corresponding structures of the device of FIGS. 1 through 3. If the piston 20' reciprocates as shown by the directional arrows and tends to creep out of the working gas space S, then the seal between the inner cylindrical surface of cylinder 19' and the end cap 84' provides the dominant flow resistance, which resistance increases when the piston 20' is at the outer extremity of its stroke FIG. 4 and presents a lesser resistance when the piston is in space S FIG. 5. This permits gas in space S to leak out of space S when the piston is in the FIG. 5 position and the working fluid in space S is high, but resists the leakage of gas when the piston is in the FIG. 4 position and the pressure of the gas in space S is lower.

The same principle obtains when the piston creeps into the working space S and the seal between end cap 82' and the cylinder wall 19' becomes the dominant gas flow resisting means. Thus the cyclic reciprocation of the piston is maintained relatively stable and the piston will tend to maintain its designed zone of reciprocation.

The following example is provided by way of illustration and is not intended as limiting of the claimed invention.

1. Length of cylinder (19)
4.300 + 0.000 inches
- 0.002
2. Internal diameter of cylinder
2.250 + 0.005 inches
- 0.0000
3. Length of piston sleeve (86)
6.000 ± 0.001 inches
4. Length of milled flats (88)
4.400 ± 0.003 inches
5. Width and depth of grooves (88)
0.010 inch

Referring to FIG. 6 of the drawing a modified form of the invention is illustrated wherein the power piston 102 is provided with milled grooves 104 in the cylindrical surface of the piston with the grooves 104 extending between upper and lower 106 and 108 nongrooved zones. The piston 102 is therefore similar in construction to piston 20 of the form of the invention shown in FIG. 1; however, in addition the cylindrical wall 110 of the cylinder 112 is provided with gas passages 114 and 116 which cooperate with the milled grooves 104 to provide the relatively more leaky zone for the assembly.

Another modified form of the present invention is shown in FIG. 7 wherein the piston 120 is provided with piston seals or rings 122 adjacent the upper end of the piston and 124 adjacent the lower end of the piston. The cylinder 126 is shaped such that in zone 130 there is a relatively close fit between the cylinder wall and the piston wall and in zones 132 and 134 the cylinder wall is enlarged to provide for the controlled leakage of gas in cooperation with the zone of the piston between rings 122 and 124.

What is new and is desired to be protected by Letters Patent is:

I claim:

1. In a free-piston Stirling cycle engine or pump having at least one free-piston mounted for reciprocation in a cylinder, a pressurized gaseous fluid maintained in the cylinder at at least one end of the free-piston the improvement comprising means associated with the cylindrical walls of the piston and the cylinder for reducing the tendency of the piston to creep into or out of the working gas space of the cylinder as it reciprocates in the cylinder, wherein the cylinder has a snug piston receiving bore and means on the cylinder or piston or both providing at least one gas passage of a length less than the length of the piston and extending in opposite directions from the mid-point of the stroke of the piston.

2. The free-piston Stirling cycle device defined in claim 1 wherein the gas passage is provided on the piston.

3. The free piston Stirling cycle device defined in claim 1 wherein the gas passage is provided in the cylindrical wall of the cylinder.

4. In a free-piston motion device having at least one free-piston mounted for reciprocation in a cylinder, a pressurized gaseous fluid maintained in the cylinder at at least one end of the free-piston the improvement comprising means associated with the cylindrical walls

of the piston and the cylinder for reducing the tendency of the piston to creep into or out of the working gas space of the cylinder as it reciprocates in the cylinder, wherein the cylinder has a snug piston receiving bore of a length less than the length of the piston and said piston is provided with at least one gas passage in the cylindrical wall thereof of a length less than the length of the piston and positioned intermediate of the piston length.

5. A method of reducing the tendency of a free-piston of a free-piston motion device to creep into or out of the working space of its cooperating cylinder comprising the steps:

forming a bore in a cylinder to snugly receive a piston within the bore; and

forming an axial gas passage in the cylindrical surface of the piston, the cylinder, or both of a length less than the length of the piston.

6. The method defined in claim 5 wherein the gas passage is formed in the cylinder.

7. The method defined in claim 5 wherein the gas passage is formed in the piston.

8. In a free-piston Stirling cycle engine or pump having at least one free power piston mounted for reciprocation in a cylinder, a pressurized gaseous fluid maintained in the cylinder at at least one end of the power piston the improvement comprising means associated with the cylindrical walls of the piston and the cylinder for reducing the tendency of the piston to creep into or out of the working space of the cylinder as it reciprocates in the cylinder, wherein the cylinder has a snug piston receiving bore of a length less than the length of the piston and said piston is provided with at least one gas passage in the cylindrical wall thereof of a length slightly greater than the piston receiving bore of the cylinder and wherein the said gas passage is of a length less than the length of the piston and positioned intermediate of the piston length.

9. A method of reducing the tendency of a free-piston of a free-piston Stirling cycle engine or pump to creep into or out of the working space of its cooperating cylinder comprising the steps:

forming a bore in a cylinder to snugly receive a working piston with the bore having a length less than the length of the piston; and

forming an axial gas passage in the cylindrical surface of the cooperating piston of a length slightly longer than the formed cylinder bore with the gas passage positioned intermediate the length of the piston.

* * * * *

Notice of Adverse Decision in Interference

In Interference No. 99,819, involving Patent No. 3,828,558, W. T. Beale, MEANS AND METHOD FOR PREVENTION OF PISTON CREEP IN FREE-PISTON RECIPROCATING DEVICE, final judgment adverse to the patentee was rendered Dec. 16, 1980, as to claims 1 and 5.

[Official Gazette April 14, 1981.]