July 11, 1961 J. G. CADIOU 2,991,773

FREE-PISTON MACHINES

Filed June 29, 1959 2 Sheets-Sheet 1

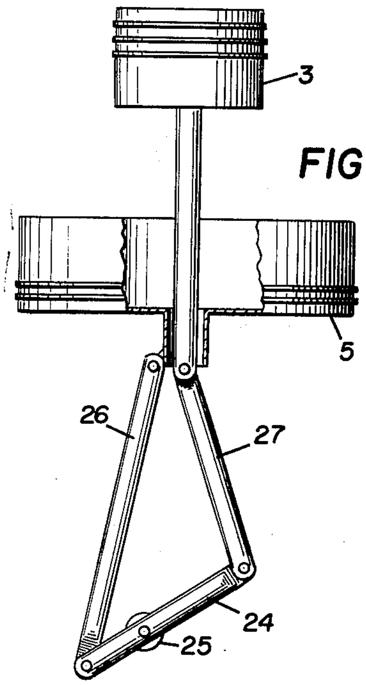


FIG 3

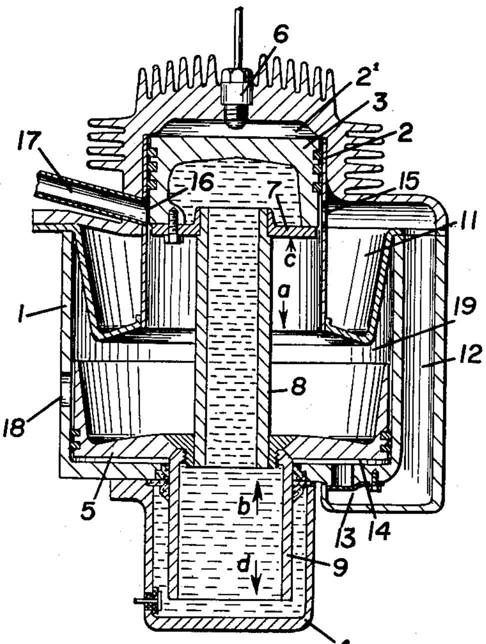


FIG 1

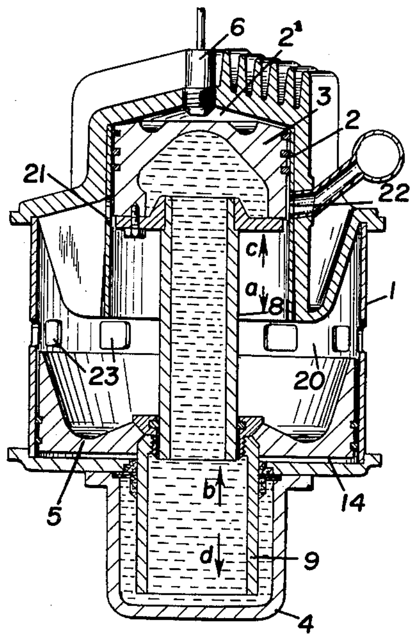


FIG 2

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FREE-PISTON MACHINES

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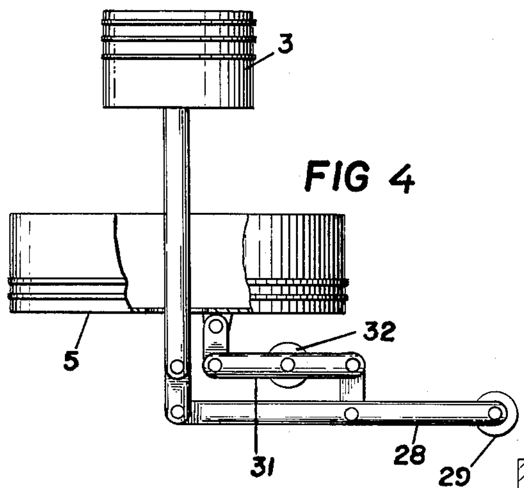


FIG 4

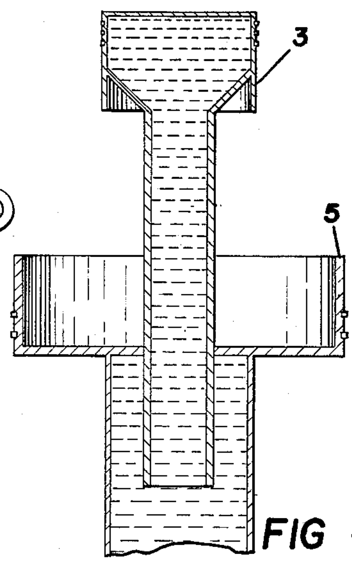


FIG 6

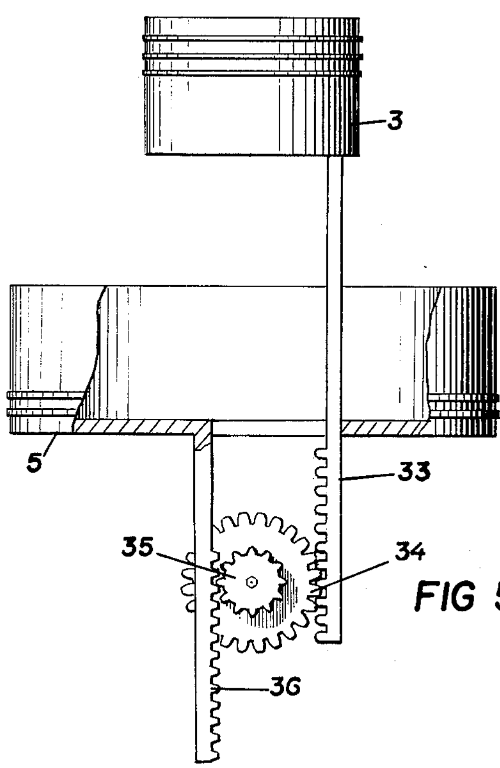


FIG 5

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# 2,991,773
# FREE-PISTON MACHINES

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6 Claims. (Cl. 123—46)

This invention relates to free-piston machines of the type comprising at least one movable element, and notably to the motor air-compressors and self-generators operating according to the free-piston principle.

It consists essentially in separating the power piston from the compressor piston and in rendering them independent of each other by adequate means, while utilizing the mass of the compressor piston for compensating the inertia effects caused by the mass of the power piston. This invention is also concerned with certain arrangements in connection more particularly with the interdependency of the two power and compressor pistons through hydraulic or mechanical means as will be explained presently in connection with the description of a few forms of embodiment of the invention which are given by way of example with reference to the accompanying drawing in which:

FIGURE 1 is an axial, diagrammatical view showing a free-piston machine constructed according to the teachings of this invention, with a hydraulic operative connection between the power piston and the compressor pistons;

FIGURE 2 illustrates a modified form of embodiment of the machine shown in FIG. 1, wherein the operative connection between the pistons is also effected by hydraulic means, and

FIGURES 3 to 6 illustrate in purely diagrammatical form other modified forms of embodiment of the machine of this invention, which incorporate mechanical connections between the pistons.

Referring first to FIG. 1, the machine illustrated therein comprises a case **1** having one one side an extension adapted to receive the cylinder **2** in which the power piston **3** is slidably mounted, and on the other side a complementary case **4**. The compressor piston **5** is movable in the first case **1**. The combustion chamber is at $2^1$ and the fuel injector at **6**. The power piston is closed by an annular partition **7** on which is secured at tubular member **8** opening on the one hand into the inner chamber of piston **3** and on the other hand, after extending through the compressor piston **5**, into the case **4**. The compressor piston **5** is rigid with a concentric piston **9** prejecting in the case **4**. This case **4** is filled with liquid, for example oil, adapted to flow through the tubular member **8** into the chamber of the power piston **3**. The cylinder **2** extends within the case **1** and is connected to a suitably shaped annular partition **10** connected in turn to the upper portion of the case **1** so as to form a chamber **11** connected in turn through a duct **12** and a non-return valve **13** to the chamber **14** of compressor piston **5**. For scavenging purposes, the chamber **11** may communicate through ports **15** formed in cylinder **2** with the inner space of this cylinder. The exhaust takes place through a port **16** formed on the cylinder **2** and leading into an exhaust pipe **17** connecting this cylinder to the turbine. Air inlet ports **18** formed in the wall of case **1** are adapted to be uncovered by the compressor piston **5**. The air is compressed at **19** in case **1** by the piston displacements, and forms air-cushions therein.

This machine operates as follows:

During the operation of the machine, the explosion produced in chamber $2^1$ forces the power piston **3** down-

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wards, that is in the direction of the arrow *a*, and causes the compressor piston **5** to travel in the opposite direction (arrow *b*), due to the compression of the liquid column formed in the case **4**, tubular member **8** and inner chamber of piston **3**.

If the cross-sectional areas of the hydraulic pistons are so calculated that the quantities of movement of these pistons are equal, no inertia effect will take place. The air will be compressed at **19** to store up the energy necessary, during the return stroke of the pistons in the direction of the arrows *c* and *d*, for compressing the air in the compressor chamber **14**, and, through the valve **13** and transfer duct $12^1$, **12**, in the annular chamber or accumulator **11**. The scavenging action takes place upon completion of the power stroke. The air from the accumulator **11** flows through the inlet ports **15** now uncovered by piston **3** and scavenges the exhaust gases from chamber $2^1$ through the exhaust ports **16** and pipe **17**.

In the modified form of embodiment illustrated in FIG. 2, the component elements similar to those shown in FIG. 1 are designated by the same reference numerals, with a few minor changes. Thus, the air is compressed in the space **20** in case **1** which lies between the pistons **3** and **5**. The inlet ports of cylinder **2** are shown at **21** and the exhaust ports at **22**. Air is admitted into the aforesaid space **20** through ports **23** uncovered by piston **5**. This machine operates as follows:

The space **20** located between the two pistons acts as a compressor. After the explosion, the power piston **3** and the compressor piston **5** move in the direction of the arrows *a* and *b* respectively, so as to compress therebetween in the aforesaid space **20** the air previously introduced through the ports **23** at the end of the preceding stroke. When the expansion of the burnt or exhaust gas moves the power piston **2** to a position in which firstly the exhaust ports **22** and then the inlet ports **21** are uncovered, a scavenging effect is obtained. The pressure exerted on piston **5**, plus the vacuum produced at **14**, causes the return stroke in the direction of the arrows *c*, *d* to begin while stopping the scavenging action, before compressing the fresh air now trapped in chamber $2^1$. It is the kinetic energy of the pistons that enable them to complete their stroke and causes at this time the space **20** (then in underpressure conditions) to communicate through the ports **23** with the surrounding atmosphere.

Therefore, the first arrangement exemplified in FIG. 1 corresponds to the conventional generators of the so-called "inward compression" or "return-stroke compression" type. The arrangement shown in FIG. 2 corresponds to the so-called "outward compression" or "outward-stroke compression" type.

The use of a single compressor piston is not critical, as the most general condition of balance is obtained if:

(1) The centers of gravity of the power and compressor elements are displaceable along a common axis;

(2) The displacements take place in opposite directions;

(3) The quantities of movement of the power and compressor elements of the machine are constantly equal.

This last requirement (3) may be obtained with a certain approximation by means of rockers or a composite rod-assembly, and with the maximum accuracy by means of rack-and-pinion assemblies or concentrical hydraulic pistons. Figures 3 to 6 illustrate these forms of embodiment.

In the case shown in FIGS. 3 and 4, a mechanical linkage is provided in the form of connecting-rods and levers between the pistons **3** and **5**. In the example shown in FIG. 3, a rocker **24** fulcrumed on a fixed pivot **25** has its ends pivoted on connecting-rods **26** and **27** connected in turn to these pistons **3** and **5** respectively.

Referring now to FIG. 4, a lever **28** pivoted at one end on a fixed fulcrum **29** has its other end connected to the rod of piston **3**, whereas a small lever **30** pivoted intermediate its ends is connected to the end of a rocker **31** pivoted at **32** on a fixed fulcrum and connected through its other end to the piston **5**.

In the modified form of embodiment illustrated in FIG. 5, the rack-forming rod **33** of piston **3** is in meshing engagement with a toothed wheel **34** rigid with another toothed wheel **35** of smaller diameter which meshes with a rack-forming rod **36** of the other piston **5**.

In the last form of embodiment of the invention which is shown in FIG. 6, the piston **3** has its rod engaged with a certain clearance in the hollow or tubular rod of piston **5** which acts as a hydraulic cylinder.

These different forms of embodiment are given only by way of example and should not be construed as limiting the invention, as many modifications may be brought thereto without departing from the spirit and scope of the invention as set forth in the appended claims.

Thus, in the case of a hydraulic construction, the following alternatives may be contemplated, inter alia:

(i) A regulation of the pressure in the compression chamber, by varying the quantity of oil stored in the case **4**.

(ii) A limitation of the piston accelerations by limiting the maximum pressure in case **4**.

(iii) The use of oil as a cooling and/or lubricating agent.

(iv) The delivery of power in the form of liquid under pressure issuing from case **4**.

The proper timing of the dead centers which is necessary for operating the injection pump may be obtained through mechanical, electrical or other means, for example as follows:

(*a*) A rod connected through a fork to the piston **5** so as to be responsive to the movement thereof.

(*b*) A variable condenser of which one armature would be the hydraulic piston **9**.



(*c*) A condenser adapted to vary under the influence of the hydraulic pressure, or the direct control of the fuel injection pump by this pressure.

I claim:

1. A machine with a free piston comprising a casing, a cylinder in said casing, a motor piston reciprocating in said cylinder, means supplying combustion gas to said cylinder, a compressor piston separated from said free piston and reciprocating in a cylinder coaxial to said first cylinder and means connecting said motor piston with said compressor piston so that said two pistons are displaced in a direction opposite to one another.

2. A machine as set forth in claim 1 in which the space of the casing comprised between the two pistons, motor and compressor, serves as the compression chamber.

3. A machine as set forth in claim 1 in which the compression chamber is located at the side of the compressor piston opposed to the motor piston.

4. A machine according to claim 1 in which said connection between the motor piston and the compressor piston is a hydraulic connection, the motor piston comprising a hollow rod which opens at the interior of a chamber provided in the motor piston and communicating with a chamber provided at the end of the casing, said hollow rod and the two above-mentioned chambers being filled with a liquid so that a displacement of the motor piston corresponds to a displacement in the opposite direction of the compressor piston.

5. In a machine as set forth in claim 1 wherein said connecting means consist of mechanical elements.

6. In a machine as set forth in claim 1 wherein the mass of the compressor piston is chosen to compensate the inertia effect due to the mass of the motor piston.

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