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(54) **FREE-PISTON ENGINE/HYDRAULIC PUMP OPERATING METHOD AND FREE-PISTON ENGINE/HYDRAULIC PUMP (EMBODIMENTS)**

(57) At the centre of this group of inventions is a method for operating a free-piston engine/hydraulic pump with at least one working volume (1), according to which the engine is started by supplying to the working mechanisms, for example a hydraulic engine (10), a hydraulic fluid held under pressure in at least one reserve volume (9), after which the fluid is injected into a hydraulic part of the working volume (1) and a piston (4) moves independently in each working volume (1) until a set fluid level is reached, whereupon an exhaust valve (3) is closed and the hydraulic fluid is displaced back to the reserve volume (9) and subsequently supplied to the working mechanisms as the piston (4) moves in the reverse direction, the exhaust valve (3) being opened once a given minimum fluid content in the working volume is reached and when the pressure has decreased to a set level, after which the hydraulic fluid is again injected into the working volume (1) to the set maximum level and the cycle is repeated. Also disclosed are two free-piston engines/hydraulic pumps, one of which operates by igniting fuel in the upper part of a working volume (1), and the other of which operates by supplying gases to the upper part of a working volume (1), said gases being held under pressure in a gas pressurizing source (24).

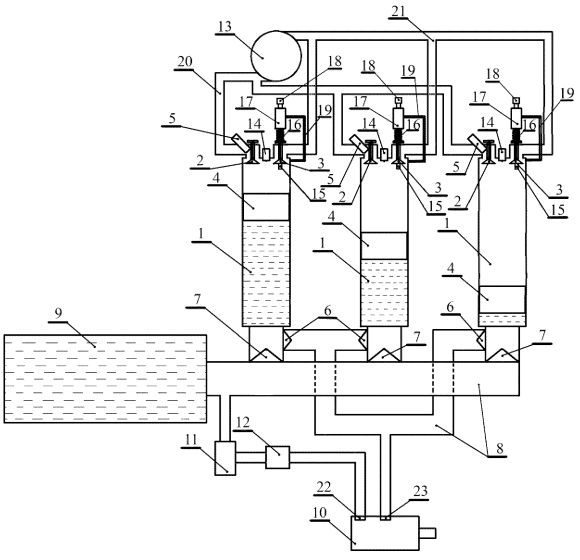

FIG. 1

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Description

Technical field to which invention relates

[0001] The invention relates to engine manufacturing and can be used in power plants of vehicles, such as boats, ships, cars and trucks, buses, airplanes etc., as well as in mobile and stationary devices that produce energy and/or perform work (gasoline generators, compressors, pumps etc.).

Indication of background art

[0002] There is known a method of operation of a free-piston engine-and-hydraulic pump (patent No. RU 2379531 dated 20.01.2010), according to which a working tank containing two oppositely moving pistons is filled with air, the air is compressed by these pistons, after which fuel is injected and the mixture burns with its subsequent expansion. In the known method, the movement of the pistons is carried out offset by a certain angle of rotation of the crankshaft, and the start of combustion is performed at a certain predetermined position of the pistons. Thus, this method has a complex system of regulation and synchronization of the movement of the pistons. An important condition for the reliable operation of a free-piston engine is a synchronous movement of the pistons throughout the entire work cycle.

[0003] There is known a method of operation of a free-piston engine-and-hydraulic pump (P.A. Shelest "Bezvalnyye generatory gasov", M..: Mashgiz, 1960, pp. 302-305), according to which the synchronization of movement of the pistons is implemented mechanically, such as by lever or gear-rack mechanisms. These mechanisms connect the pistons in such a way that when one of them moves in one direction in the working tank, the other moves in the opposite direction. The main disadvantage of the mechanical method of synchronizing the movement of the pistons is its complexity, the presence of the synchronizer having a significant mass and the loss of energy for its driving, which negatively affects the engine power.

[0004] Closest to the claimed method is the method of operation of a free-piston engine-and-hydraulic pump (patent No. UA 92483 dated 26.08.2014), which is selected as a prototype. The known method of operation of a free-piston engine-and-hydraulic pump consisting of four working tanks, each of which contains a free piston, inlet and outlet valves, inlet and outlet hydraulic valves, includes starting operation of the engine-and-hydraulic pump by connecting a starting device, pumping hydraulic fluid which sets the free piston in motion, closing the outlet valve, starting the work process in the working tank, closing the inlet valve, gas pressure occurrence in the working tank, gas pressure on the free piston, movement of the piston in the opposite direction, opening the outlet valve and opening the inlet valve, the operation of which is carried out using a distributing shaft.

Technical problem to be solved

[0005] In the known method, the implementation of the starting of the engine-and-hydraulic pump occurs with the help of an additional starting system, which has a complex configuration and requires a lot of additional equipment. This greatly complicates the starting and operation of the engine. At the same time,

the operation of the engine does not depend on hydraulic mechanisms. In addition,
the method chosen as the prototype includes forced regulation of the movement of
the pistons and their synchronization throughout the entire operation of the engine.

[0006] Such synchronization of the movement of the pistons is implemented by that the free pistons are connected in pairs by a hydraulic connection. Therefore, this method has a complex system for starting the engine and requires a system for regulating and synchronizing the movement of free pistons throughout the entire work cycle.

[0007] The invention is based on the task of simplifying the starting of a free-piston engine-and-hydraulic pump operation and eliminating a process of regulating and synchronizing the movement of free pistons. So that there is no need to use additional starting and synchronization systems to start and operate the engine. The task of the invention is solved by the method of operation of a free-piston engine-and-hydraulic pump, which is being patented.

Disclosure of invention

[0008] The method of operation of a free-piston engine-and-hydraulic pump, with at least one working tank 1 with inlet 2 and outlet 3 valves through which air and exhaust gases flow, inlet 6 and outlet 7 hydraulic valves, and a free piston 4, includes starting the operation of the engine-and-hydraulic pump, pumping hydraulic fluid which drives the free piston 4, closing the outlet valve 3, starting the work process in the working tank 1, closing the inlet valve 2, generating gas pressure in the working tank 1, acting of gas pressure on the free piston 4, movement of the piston in the opposite direction, opening the outlet valve 3 and opening the inlet valve 2. The start of the operation of the engine-and-hydraulic pump is started by opening a shut-off and control valve 12, which restrains the pressure of the hydraulic fluid located in at least one high- pressure tank 9. Upon the shut-off and control valve 12 opening, the hydraulic fluid is supplied to the hydraulic mechanisms 10 that leads to performing, in over a certain time, useful work. After which the volume of fluid in the high-pressure tank 9 is replenished again, and is always maintained at a certain required level due to operation of a working tank 1 with a free piston 4. Since the waste hydraulic fluid supplied from the working mech-

anisms 10 is pumped into the hydraulic part of the working tank 1, it leads to the movement of the free piston 4 and after reaching a certain maximum level of fluid, the working process starts in the working tank 1, and the gas pressure is generated.

[0009] After which, due to the gas pressure in the working tank 1, the hydraulic fluid is pumped into the high-pressure storage tank 9 under high pressure, returning the used volume of fluid into the high-pressure storage tank 9. This cycle is repeated as long as the shut-off and control valve 12 remains open. But as soon as the shut-off and control valve 12 is closed, the decrease in the volume of fluid in the high-pressure tank 9 stops, but always remains at a sufficiently high level so that when the shut-off and control valve 12 is reopened, the volume and pressure of hydraulic fluid is sufficient to perform useful work by hydraulic mechanisms 10, until the working tank 1 operates and replenishes the lost volume. Herein, when using one working tank 1, at the moment when the working process is carried out in it, the waste fluid is pumped into a low-pressure storage tank 9 (shown on the left in Figure 2), and when using more than one working tank 1, the function of the low-pressure storage tank 9 (shown on the left in Figure 2) can also be performed alternately by working tanks 1.

[0010] Also, when using more than one working tank 1, moving the free piston 4 until the specified maximum liquid level is reached, performed separately in each working tank 1, after which the outlet valve 3 is closed. Moreover, when the free piston 4 moves in the opposite direction, hydraulic fluid is forced back into the high-pressure storage tank 9, replenishing the lost volume and supplied to the working mechanisms 10, and after reaching a certain minimum fluid content in
each separate working tank 1 and at the moment the pressure drops to a predetermined level, the outlet valve 3 of the gas part of the working tank 1 is opened, which leads to a decrease in pressure in the working tank 1, and the hydraulic fluid is again pumped into this working tank 1 to a predetermined maximum level, and the cycle is repeated.

[0011] The simplification of the starting of the engine being patented is realized due
to that the operation of the hydraulic mechanisms 10 starts from the pre-accumulated pressure kinetic energy that is restrained in the high-pressure storage tank 9 by the shut-off and control valve 12. Also due to that when using several working tanks 1, the start of the work process in each individual working tank 1 depends on the maximum filling of this tank with the hydraulic fluid, engine operation is simplified. In addition, in the claimed method, when there is more than one working tank 1, each free piston 4 operates on one's own in its working tank 1 and is not associated with the operation of the other free pistons 4 in the other working tanks 1.

[0012] Therefore, in the proposed method, there is no need to regulate and synchronize the movement of the ree pistons 4.

Description of the first method of carrying out the invention

[0013] The task is solved by a design of a first variant of a free-piston engine-and-hydraulic pump being patented. The free-piston engine-and-hydraulic pump contains at least one working tank 1 with inlet 2 and outlet 3 valves, a free piston4,
an injection 5 and ignition 14 system, inlet 6 and outlet 7 hydraulic valves, and a pipeline 8. At the same time, the proposed engine-and-hydraulic pump additionally contains at least one high-pressure storage tank 9 connected to hydraulic part of the working tank 1 and, through the shut-off and control valve 12 and the gearbox, to hydraulic mechanisms 10, and at least one low-pressure hydraulic storage tank 9 connected to the outlet of the hydraulic mechanisms 10 and the inlet of the hydraulic part of the working tank 1, wherein, if there is more than one working tank 1, the function of the low-pressure storage tank 9 is performed by a working tank 1 with an open outlet valve 3, a turbocharger connected to inlet 20 and outlet 21 air channels of the working tank 1, furthermore, the free piston 4 divides the working tank 1 into gas and hydraulic parts of variable volume, and the outlet valve 3 comprises a protrusion 15 of a given height located on the valve 3 inside the gas part of the working tank 1 and protruding towards the free piston 4, a start contact 18, a control element 16 and a pressure compensation device 17 connected by a channel to the working tank 1 are arranged on the outside of the outlet valve3.

Description of the second method of carrying out the invention

[0014] Another variant of achieving the specified task of the invention is a free-piston engine-and-hydraulic pump that uses compressed air or steam pressure as an energy source, comprising at least one working tank 1 with inlet 2 and outlet 3 valves, a free piston 4 and inlet 6 and outlet 7 hydraulic valves, and a pipeline 8. The proposed free-piston engine-hydraulic pump additionally contains at least one high-pressure storage tank 9, which is connected to the hydraulic part of the working tank 1 and through shut-off and control valve 12 and reducer 11, to hydraulic mechanisms 10. In addition, there is a low pressure storage tank 9 (shown on the left in Figure 2), which is connected to the outlet 23 of the hydraulic mechanism 10, as well as to the inlet of the hydraulic part of the working tank 1. An outlet air channel 21 and an inlet air channel 20 connected to a gas pressure source 24. At the same time, the working tank 1 is equipped with sensors 25, 26 for monitoring maximum and minimum fluid content, and the free piston 4 divides the working tank 1 into gas and hydraulic parts of a variable volume. Furthermore, the inlet 2 and outlet 3 valves are equipped with a control element. In the embodiment of the second variant of the engine, the control element is made in the form of an electromagnet. In this case, the opening and

closing of the inlet 2 and outlet 3 valve depends on the operation of the sensors 25, 26 for monitoring the upper and lower position of the free piston 4, which trigger the electromagnets. Also, when using more than one working tank 1, in the second embodiment of the engine, for starting, instead of storing hydraulic fluid in a high-pressure storage tank 9, the volume of fluid can be used that, when the engine is stopped, remains in any of the working tanks 1, supplying pre-accumulated pressure gases into this working tank 1, due to which, at the moment of starting, the working tank 1 will perform the function of a high-pressure storage tank 9.

[0015] In both declared versions of the free-piston motor-hydraulic pump, the working mechanisms 10 are activated by the presence of pre-accumulated kinetic energy of pressure in the high-pressure storage tank 9.

[0016] After which, thanks to the waste hydraulic fluid coming from the outlet 23 working mechanisms 10, the free piston 4 moves until the required maximum liquid level in the working tank 1 is reached, which leads to activation of this working tank 1. And after the start of the working process in the working tank 1 and the occurrence of gas pressure in the gas part of the working tank 1, the free piston 4 begins to put pressure on the hydraulic fluid and push it back into the high-pressure storage tank 9, from where the hydraulic fluid will flow again to the working mechanisms 10 through the gearbox 11 and shut-off and control valve 12, and the cycle is repeated. The frequency of repetition of the cycle occurs automatically and depends on the speed of filling the working tanks 1 with the waste fluid.

[0017] Moreover, the proposed variants of a free-piston engine-and-hydraulic pump allow the use of an unlimited number of working tanks 1, as well as the development of modular engines with the possibility of increasing the power of an existing engine. Such embodiment is possible by adding additional working tanks and using a high-pressure storage tank 9 with a higher pressure.

[0018] If necessary, the use of both variants of the free-piston engine being patented
in one engine allows to create a hybrid engine that can use both combustible fuel and compressed air for operation.

[0019] It should be noted that when adding additional pipelines and a hydraulic distributor to the proposed engine-and-hydraulic pump variants, it is possible to implement the opposite effect. In this case, the rotational movement of the hydraulic engine 10 will lead to the reciprocating movement of the free piston 4 in the working tank 1, leading to compression of air in the gas part of the working tank 1 and its further accumulation. This allows the engine to operate as a high-pressure pneumatic compressor and also offers the possibility of energy recovery for use in vehicles, for example.

[0020] The technical essence of the invention is represented by figures and examples of specific embodiments. The given variants of a free-piston engine-and-hydraulic pump, their design and principle of operation, also reveal the essence of the method that is claimed.

Brief description of drawings

[0021]

Figure 1 shows a schematic diagram of a fuel-powered free-piston 4 engine-and-hydraulic pump with three working tanks 1 and an outlet valve 3 provided with a protrusion 15, a start contact 18, a control element 16 and a pressure compensation device 17 connected by a channel to the working tank 1.

The examples presented are not to be considered as limiting the invention. A free-piston engine-and-hydraulic pump (see Figure 1) consists of three working tanks 1, each of which having inlet 2 and outlet 3 valves, a free piston 4, a nozzle 5 for fuel injection, and inlet 6 and outlet hydraulic 7 valves. The engine-and-hydraulic pump also contains a pipeline 8 (high and low pressure), one high-pressure storage tank 9 with hydraulic fluid, which is connected by the pipeline 8 (which is a high-pressure pipeline) to the working tanks 1, a working mechanism 10 made in the form of a hydraulic motor connected to the high-pressure storage tank 9 via a gearbox 11 and a shut-off and control valve 12, a turbocharger 13. The function of a low-pressure storage tank is performed by the working tanks 1 with the open outlet valve 3. Here, the free piston 4 divides the working tank 1 into gas and hydraulic parts. The gas part contains the nozzle 5 for fuel injection, an ignition device 14, the inlet 2 and outlet 3 valves. The hydraulic part contains the inlet 6 and outlet 7 hydraulic valves. In addition, the outlet valve 3 is provided with a protrusion 15, which is located on the side of the gas part of the working tank 1, as well as a control element 16 made in the form of a spring, a pressure compensation device 17 made in the form of a pneumatic cylinder, and a start contact 18. Moreover, the pneumatic cylinder 17 is connected by a channel 19 to the gas part of the working tank 1. The turbocharger 13 is connected to the working tanks by inlet 20 and outlet 21 channels. In addition, the hydraulic motor 10 is equipped with an inlet 22 and an outlet 23 which through pipeline 8 (which is a low pressure pipeline) connected to hydraulic inlet valves 6

Figure 2 shows a schematic diagram of a free-piston engine-and-hydraulic pump with one working tank 1 containing sensors 25, 26 for monitoring maximum and minimum fluid content, which uses compressed air as an energy source.

[0022] A free-piston engine-and-hydraulic pump (see Figure 2) consists of one working tank 1 with inlet 2 and outlet 3 valves, each of which has a control element in the form of an electromagnet (not shown in Figure 2), a free piston 4, a gas pressure source 24 made in the form

of a high-pressure cylinder, and inlet 6 and outlet 7 hydraulic valves. Also, the engine-and-hydraulic pump contains a pipeline 8, two storage tanks 9 with hydraulic fluid, one of which is a low- pressure storage tank (shown on the left in Figure 2), and the other is a high- pressure storage tank (shown on the right in Figure 2). The high-pressure storage tank 9 is connected to the working tank 1 by pipeline 8 (which is a high-pressure pipeline). The low pressure tank 9 is connected to the working tank 1 by a pipeline 8 (which is a low pressure pipeline). Moreover, the engine-and- hydraulic pump contains a working mechanism 10 made in the form of a hydraulic motor connected to the high-pressure storage tank 9 through a gearbox 11 and a shut-off and control valve 12. The hydraulic motor 10 is provided with an inlet 22 and an outlet 23 and is connected by the low pressure pipeline 8 with the inlet hydraulic valve 6 and the low- pressure tank 9. Here, the free piston 4 divides the working tank 1 into gas and hydraulic parts. The gas part contains the inlet 2 and outlet 3 valves with a control element in the form of an electromagnet. The hydraulic part contains the inlet 6 and outlet 7 hydraulic valves. In addition, the working tank 1 contains a sensor 25 for monitoring an upper position and a sensor 26 for monitoring a lower position of the free piston.

Description of at least one way of carrying out the invention

[0023] The free-piston engine-and-hydraulic pump (Figure 1) works as follows.

[0024] The operation of the engine-and-hydraulic pump is started due to opening the shut-off and control valve 12 and the supply of the hydraulic fluid stored under pressure in the high-pressure storage tank 9, which is supplied through the gearbox 11 into the inlet 22 of the hydraulic motor 10 where the hydraulic energy of the fluid is converted into mechanical energy. Having transferred the energy, the hydraulic fluid exits through the outlet 23 of the hydraulic motor 10 via the pipeline 8 (which is a low pressure pipeline) to the inlet hydraulic valves 6 of the three working tanks 1. While the exhaust valve 3 is in the open position, the gases in the gas part of the working tank freely exit until the working fluid raises the piston 4 to a position in which the piston presses on the protrusion 15 of the outlet valve 3 and closes it. The moment of closing of the outlet valve 3 depends on the pushing by the free piston 4 of the protrusion 15 on the outlet valve. This leads to the closing of the start contact 18 in the working tank 1 which has reached its maximum filling. When the start contact 18 closes, the nozzle 5 is activated, injecting fuel. After that, the ignition device 14 is activated, which is made in the form of a spark plug, and ignites the fuel mixture. The energy of the expanded gases affects the piston 4 which puts pressure on the hydraulic fluid. The hydraulic fluid returns to the high-pressure storage tank 9 through the outlet 7 hydraulic valve and the pipeline 8 (which is a high-pressure pipeline). Also, the pressure of the hydraulic fluid closes the inlet 6 hydraulic valve of the working tank 1 in which the start of the work process was triggered and thus, the hydraulic fluid flows from the working mechanisms through the inlet 6 hydraulic valve only to the unfilled working tanks 1. Also, the resulting gas pressure closes the inlet valve 2 and the outlet valve 3 which is also affected by the pressure of the pneumatic cylinder 17 which is connected to the gas part of the working tank through the channel 19. The channel 19 connecting the working tank with the pneumatic cylinder 17 of the outlet valve balances the pressure in such a way that the pressure force from the working tank on the closed outlet valve 3 is close to the pressure force of the pneumatic cylinder 17 on the valve from the outside. Therefore, the force of pressure on the outlet valve 3 from the inside is partially balanced with the pressure on the valve 3 from the outside. Due to this, when the pressure level in the working tank 1, in which ignition occurred (for example, in the working tank 1 positioned on the left in Figure 1), drops to a predetermined level, the control element 16 opens the outlet valve 3 and the exhaust gases flow through the outlet channel 21 to the turbocharger 13 which pumps air through the inlet channel 20. This leads to opening of the inlet valve 2 and blowing of the gas part in the working tanks 1 which have not reached the maximum filling yet. By reducing the pressure in the working tank 1 (positioned on the left in Figure 1), the hydraulic fluid from the working mechanisms fills the hydraulic part of the working tank 1 through the inlet hydraulic 6 valve again, raising the piston 4 to the activation point. Therefore, each working tank 1 is activated only when its hydraulic part is maximally filled with the hydraulic fluid, independently of the other working tanks. The frequency of repetition of the cycle depends on the rate of consumption of the hydraulic fluid from the high-pressure storage tank 9 by the working mechanisms and subsequent filling of all three working tanks 1. The moment of the start in the working tank 1 is automatically repeated at each specified maximum filling of the working tank 1 with the hydraulic fluid, and each piston 4 in its separate working tank 1 works independently of the other pistons 4 in the other working tanks, so there is no need to synchronize them.

[0025] The free-piston engine-and-hydraulic pump (Figure 2) works as follows.

[0026] The operation of the engine-and-hydraulic pump is started due to opening the shut-off and control valve 12 and the supply of the hydraulic fluid stored under pressure in the high-pressure storage tank 9, which is supplied under pressure through the gearbox 11 into the inlet 22 of the hydraulic motor 10, where the hydraulic energy of the fluid is converted into mechanical energy. Having transferred the energy, the fluid exits through the outlet 23 via the pipeline 8 (which is a low pressure pipeline) to the inlet hydraulic valve 6 of the working tank 1. While the outlet valve 3 is in the open position, the air in the gas part of the working tank freely exits until the hydraulic fluid raises the free piston 4 to the required max-

imum level. At the moment the predetermined maximum fluid level is reached, the sensor 25 for monitoring the upper position of the piston 4 is triggered, which activates the electromagnet which closes the outlet valve 3 and opens, for a certain time, the inlet valve 2. Compressed air from the gas pressure source 24 enters the gas part of the working tank 1. The compressed air exerts pressure on the free piston 4 which acts on the hydraulic fluid. The fluid enters the high-pressure storage tank 9 through the outlet hydraulic valve 7 and the pipeline 8 (which is a high-pressure pipeline). Also, the pressure of the hydraulic fluid closes the inlet 6 hydraulic valve of the working tank 1. Therefore, the hydraulic fluid coming from the hydraulic motor 10 through the pipeline 8 (which is a low pressure pipeline) enters the low-pressure storage tank 9. At the moment when the free piston 4 reaches the required predetermined lower level, the sensor 26 for monitoring the lower position is triggered, which activates the electromagnet and opens the outlet valve 3 and the exhaust gases exit through the outlet channel 21. Due to the decrease in pressure in the working tank 1, the hydraulic fluid from the low-pressure storage tank 9 fills the hydraulic part of the working tank 1 through the hydraulic inlet valve 6, again raising the piston 4 to the activation point. The frequency of repetition of the cycle depends on the rate of consumption of the hydraulic fluid by the working mechanisms from the high-pressure storage tank 9 and the filling of the working tank 1. The moment of starting the working tank 1 is automatically repeated for each specified maximum filling of the working tank 1 with the hydraulic fluid. In this case, the inventive engine operates as a pneumatic engine. If a heated steam is supplied to the gas part of the working tank 1 instead of the compressed air, then the proposed engine-and-hydraulic pump can be used as an external combustion engine.

[0027] Thus, the proposed distinctive features of the two variants of a free-piston engine-and-hydraulic pump and the method of their operation greatly simplify starting of the engine and eliminate the need for the process of regulating and synchronizing of the movement of free pistons.

Claims

1. A method of operation of a free-piston engine-and-hydraulic pump with at least one working tank with inlet and outlet valves through which air and exhaust gases flow, inlet and outlet hydraulic valves and a free piston, the method comprising starting the operation of the engine-and-hydraulic pump, pumping a hydraulic fluid which drives the free piston, closing the outlet valve, starting a working process in the working tank, closing the inlet valve, generating gas pressure in the working tank, acting of the gas pressure on the free piston, moving the piston in an opposite direction, opening the outlet valve and opening the inlet valve, **characterized in that** the operation of the engine-and-hydraulic pump is started by supplying to the working mechanisms of the hydraulic fluid which is stored under pressure in at least one storage tank and which, after performing the work, is injected into a hydraulic part of the working tank, wherein the piston is moved independently in each individual working tank until a predetermined fluid level is reached, after which the outlet valve is closed, and wherein, when the piston moves in the opposite direction the hydraulic fluid is forced back into the storage tank and supplied into the working mechanisms, and the outlet valve is opened after reaching a certain minimum fluid content in the working tank and at the moment the pressure drops to a predetermined level, which leads to a decrease in pressure in the working tank, and the hydraulic fluid is pumped again into the working tank to a predetermined maximum level, and the cycle is repeated.

2. A free-piston engine-and-hydraulic pump comprising at least one working tank with inlet and outlet valves, a free piston, an injection and ignition system, inlet and outlet hydraulic valves, and a pipeline, **characterized by** further comprising at least one storage tank with a hydraulic fluid which is supplied under pressure to the working mechanisms, a gearbox, a shut-off and control valve, a turbocharger, inlet and outlet air channels, and wherein the free piston divides the working tank into gas and hydraulic parts of variable volume, and the outlet valve comprises a protrusion, a start contact, a control element and a pressure compensation device connected by a channel to the working tank.

3. A free-piston engine-and-hydraulic pump comprising at least one working tank with inlet and outlet valves, a free piston and inlet and outlet hydraulic valves, and a pipeline, **characterized by** further comprising at least one storage tank with a hydraulic fluid which is supplied under pressure to the working mechanisms, a gearbox, a shut-off and control valve, an outlet air channel and an inlet air channel connected to a gas pressure source, wherein the working tank is equipped with sensors for monitoring maximum and minimum fluid content, and the free piston divides the working tank into gas and hydraulic parts of variable volume, and wherein the inlet and outlet valves are equipped with control elements.

Amended claims under Art. 19.1 PCT

1. A method of starting and operation of a free-piston engine-and-hydraulic pump with at least one working tank with inlet and outlet valves through which air and exhaust gases flow, inlet and outlet hydraulic valves and a free piston, the method comprising

starting the operation of the engine-and-hydraulic pump, pumping a hydraulic fluid which drives the free piston, closing the outlet valve, starting a working process in the working tank, closing the inlet valve, generating gas pressure in the working tank, acting of the gas pressure on the free piston, moving the piston in an opposite direction, opening the outlet valve and opening the inlet valve, **characterized in that** the operation of the engine-and-hydraulic pump is started by supplying to the hydraulic mechanisms of the hydraulic fluid which is stored under pressure in at least one high-pressure storage tank, after which the engine-and-hydraulic pump is started due to the pumping of this hydraulic fluid, which has already performed useful work, into a hydraulic part of the working tank of the engine-and-hydraulic pump, which will lead to the movement of the free piston in the working tank with an open outlet valve until a predetermined maximum hydraulic fluid level is reached, after which the outlet valve is closed and the working process in the working tank is started, wherein, when the piston moves in the opposite direction the hydraulic fluid is forced again into the high-pressure storage tank and supplied to the hydraulic mechanisms, and the outlet valve is opened after reaching a predetermined minimum fluid content in the working tank or at the moment the pressure drops to a predetermined level, which leads to a pressure relief in the working tank, and the hydraulic fluid is pumped again into the working tank to a predetermined maximum level, and the cycle is repeated.

2. A free-piston engine-and-hydraulic pump comprising at least one working tank with inlet and outlet valves, a free piston, an injection and ignition system, inlet and outlet hydraulic valves, and a pipeline, **characterized by** further comprising at least one high-pressure storage tank, a gearbox, a shut-off and control valve, a turbocharger, inlet and outlet air channels, and wherein the free piston divides the working tank into gas and hydraulic parts of variable volume, and the outlet valve comprises a protrusion, a start contact, a control element and a pressure compensation device connected by a channel to the working tank.

3. A free-piston engine-and-hydraulic pump comprising at least one working tank with inlet and outlet valves, a free piston and inlet and outlet hydraulic valves, and a pipeline, **characterized by** further comprising at least one high-pressure storage tank and low-pressure storage tank, a gearbox, a shut-off and control valve, an outlet air channel and an inlet air channel connected to a gas pressure source, wherein the working tank is equipped with sensors for monitoring maximum and minimum fluid content, and the free piston divides the working tank into gas and hydraulic parts of variable volume, and wherein the inlet and outlet valves are equipped with control elements.

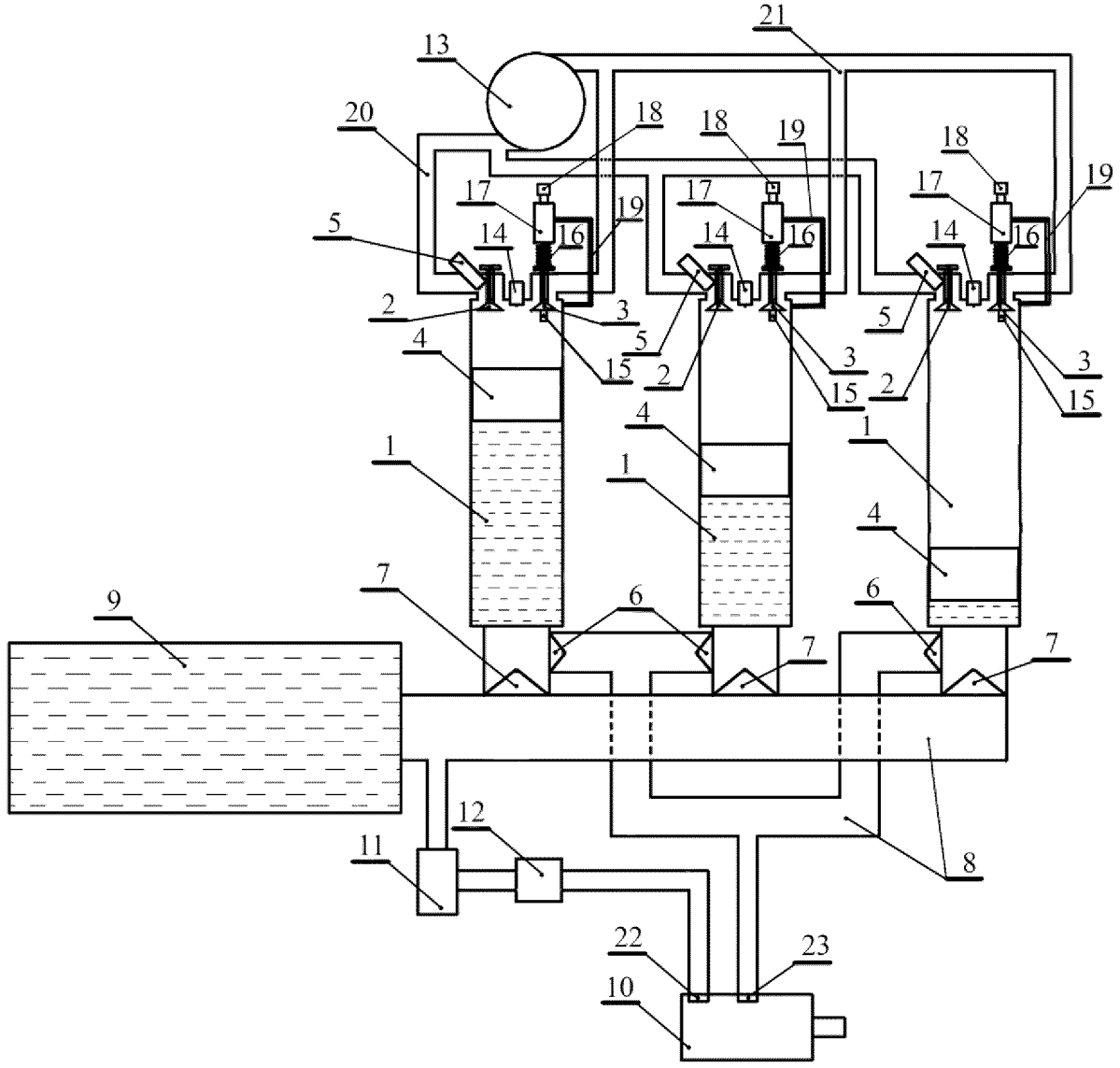
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FIG. 1

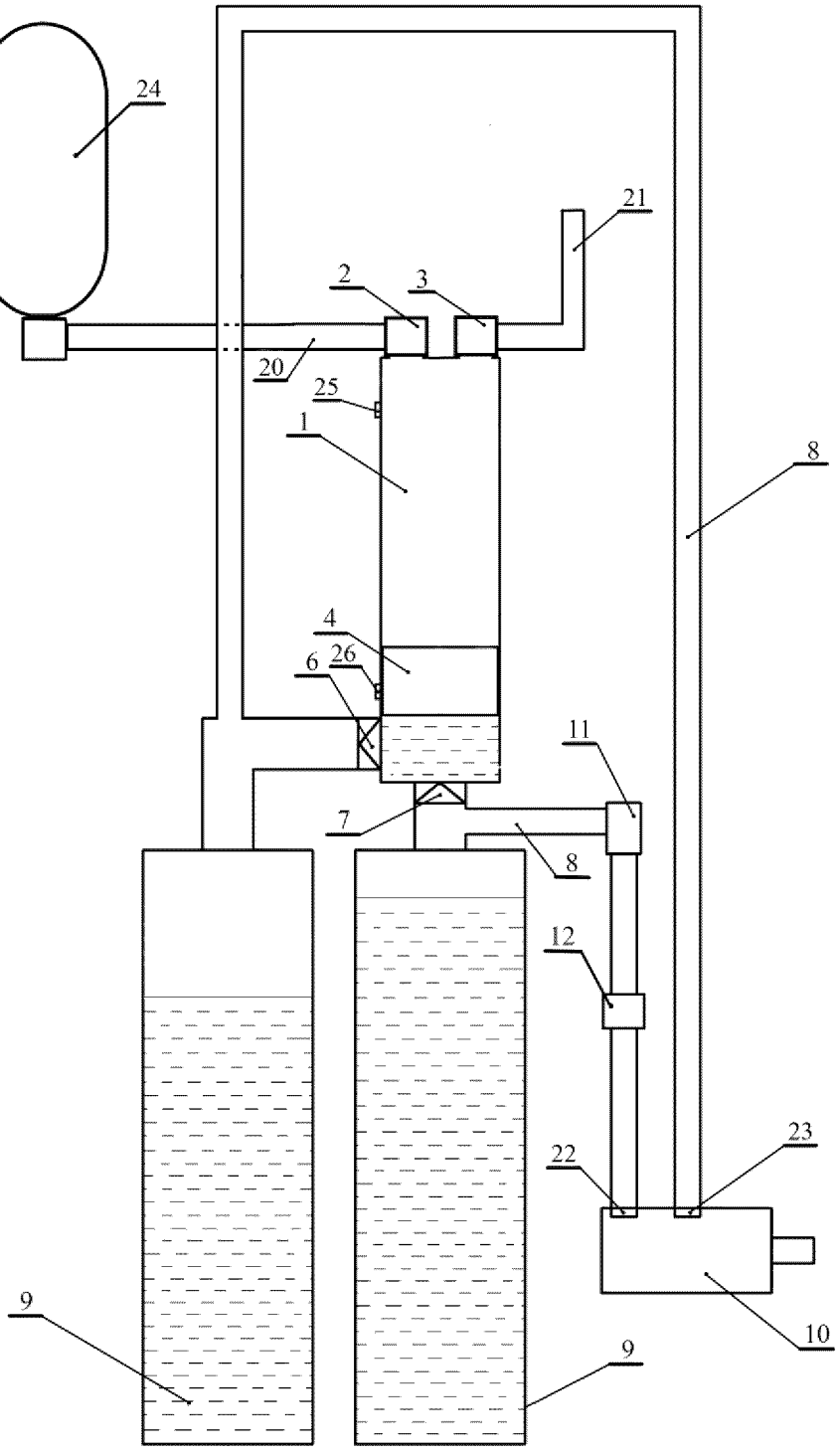

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/UA 2022/000013

A. CLASSIFICATION OF SUBJECT MATTER
F02B 71/04; 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)
F02B 71/04; F02B 71/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 3560115 A (ERIC A SALO [US]), 02 February 1971 (02.02.1971), fig. 1-9, column 5-8 description	1 2, 3
Y A	GB 1511423 A (TECHNION RES & DEV FOUNDATION [IL]), 17 May 1978 (17.05.1978), fig. 1, 2	1 2, 3
Y A	RU 2050449 C1 (SAMPAUER OJ [FI]), 20 December 1995 (20.12.1995), fig. 1	1 2, 3
Y A	CN 100419214 C (UNIV TSINGHUA GRADUATE SCHOOL [CN]), 17 September 2008 (17.09.2008), fig. 1-4	1 2, 3
Y A	CN 101372913 A (UNIV TSINGHUA GRADUATE SCHOOL [CN]), 25 February 2009 (25.02.2009), fig. 1-4	1 2, 3

☒ Further documents are listed in the continuation of Box C. ☒ 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
"E" earlier application or patent but published on or after the international filing date
"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
07 July 2022 (07.07.2022)	21 July 2022 (21.07.2022)
Name and mailing address of the ISA/ UA Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/UA 2022/000013

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
D, A	UA 92483 U (HOLOVCHUK ANDRII FEDOROVYCH [UA]), 26 August 2014 (26.08.2014), whole document	1-3
A	US 4205638 A (VLACANCINCH GIOVANNI [US]), 03 June 1980 (03.06.1980), fig. 1, 2	1-3
A	IP N07279683 A (TABUCHI ZENICHI [JP]), 27 October 1995 (27.10.1995), abstract and drawing	1-3
A	FR 2585769 A1 (MALHERBE ANDRE [FR]), 06 February 1987 (06.02.1987), abstract and fig. 5	1-3

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/UA 2022/000013

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See supplemental sheets

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☒ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (2)) (January 2015)

INTERNATIONAL SEARCH REPORT

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Box III

The set of claims in this invention comprises three independent claims, and thus the international application relates to a group of inventions (cf. PCT Rule 13.1).

With regard to PCT Rule 13.2, where a group of inventions is claimed in one and the same international application, the requirement of unity of invention referred to in Rule 13.1 shall be fulfilled only when there is a technical relationship among those inventions involving one or more of the same or corresponding special technical features. The expression "special technical features" shall mean those technical features that define a contribution which each of the claimed inventions, considered as a whole, makes over the prior art.

The claimed inventions according to claims 1, 2 and 3 characterise a "method for operating a free-piston engine/hydraulic pump" (claim 1) and two types of "free-piston engine/hydraulic pump" (claims 2 and 3 respectively), each of which is characterised by the presence of at least one working volume, inlet and outlet valves for air and exhaust gases, hydraulic inlet and outlet valves, a pipeline, air channels, a free piston and at least one reserve volume containing a hydraulic fluid which is supplied under pressure to the working mechanisms. Furthermore, the method according to claim 1 and the "engine" according to claim 2 are characterised by the presence of steps and means of igniting a fuel, and the "engines" claimed in claims 2 and 3 comprise a reduction gear and a shut-off control valve, wherein an outlet valve comprises a regulator element (in claim 2 there is no mention of the presence of regulator elements on the inlet valve as in claim 3).

It is clear from the description of the claimed group of inventions that they are all directed toward simplifying the start-up operation of such engines and do not include any process of regulation or synchronisation of the movement of the free (independent) pistons.

The technical relationship among the stated inventions involves common technical features which characterise the presence of an additional reserve volume containing a hydraulic fluid which is supplied under pressure to the working mechanisms.

It should also be noted that the method according to claim 1 is not characterised by specific design aspects of an outlet valve having a projection (as in claim 2) or the presence of sensors for monitoring maximum and minimum fluid contents in the working volume (as stated in claim 3), the stated design forms of the valve synchronising elements being completely different and having an effect on the achievement of completely different technical results.

Document US 3560115 A from 2 February 1971 (D1) discloses a method for operating a free-piston engine/hydraulic pump (in which, during operation, after igniting the fuel in a combustion chamber (34), a free piston (24) displaces a fluid which is provided in a hydraulic chamber (36)) having at least one working volume (22) with an inlet (72+202a) and an outlet (50) valve through which air (27) and exhaust gases (41) can overflow, an inlet (40+62) and outlet (120) hydraulic valve and a free piston (24), said method involving starting the operation of the engine/hydraulic pump, pumping a hydraulic fluid (along line (40), said fluid being pressurised; cf. column 5 of the description, second paragraph) which drives the free piston (24), closing the outlet valve (50), starting the operating process in the working volume, closing the inlet valve (72+202a), building gas (34) pressure in the working volume (22), the pressure of the gases on the free piston (24) moving the piston in the reverse direction (cf. column 5 of the description), and opening the outlet and the inlet valves (cf.

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column 5 of the description). Operation of the engine/hydraulic pump is started by supplying a hydraulic fluid to the working mechanisms, which fluid is kept under pressure (along line (40)), wherein the movement of the piston (24) is independent (cf. figures 1 and 9) in each separate working volume (22) until the moment a specified (cf. column 5 of the description, lines 18-20) level of fluid (42) is reached, and once this has been reached closing the outlet valve (50) (cf. column 5 of the description, lines 18-24). As the piston (24) moves in the reverse direction the hydraulic fluid is displaced and supplied (122, 146, 124, 150) to the working mechanisms (10), and the outlet valve (50) is opened once a specified minimum fluid content in the working volume is reached, and at the moment the pressure decreases to a specified level (cf. column 8 of the description, lines 35-38) which produces a decrease in pressure in the working volume, the hydraulic fluid is again pumped into the working volume to a specified maximum level (42) and the cycle is repeated.

Document D1 does not disclose any features characterising starting the operation of an engine/hydraulic pump which is carried out by supplying a hydraulic fluid to the working mechanisms, which fluid is kept under pressure in at least one reserve volume and which, after operation is implemented, is pumped into a hydraulic part of the working volume, and, accordingly, said document does not disclose features which characterise displacing the hydraulic fluid back into the reserve volume.

Document GB 1511423 A from 17 May 1978 (D2) discloses a method for operating a free piston engine/hydraulic pump, in which the piston (11, 11') moves independently (analogously to how it is presented in the claimed invention and depicted in figure 1) in each separate working volume (1, 2), where operation of the engine/hydraulic pump is also started by supplying a hydraulic fluid to the working mechanisms (from the accumulator tanks 6 and 6' respectively), which fluid is kept under pressure in at least one reserve volume (6, 6') and which, once operation is implemented, is pumped into a hydraulic part (13, 13') of the working volumes (1, 2). Document D2 also discloses that as the piston (11, 11') moves in the reverse direction, the hydraulic fluid is displaced back into the reserve volume (6, 6') and supplied (101, 102, 103) to the working mechanisms (5) (cf. the corresponding text in the description: "since high-pressure fluid is not available at the moment depicted, the high-pressure line 102 is fed fluid from the accumulator 6 which drives the motor 5 via the control valve 4").

Taking into account the above-mentioned information, the possibility becomes obvious to a person skilled in the art of devising a method for operating a free-piston engine/hydraulic pump, known from document D1, in which the operation of the engine/hydraulic pump can be started by supplying a hydraulic fluid to the working mechanisms, which fluid is kept under pressure in at least one reserve volume and which, once operation is implemented, is pumped into a hydraulic part of the working volume with subsequent displacement of the hydraulic fluid back into the reserve volume, as described in document D2. Moreover, the possibility becomes obvious to a person skilled in the art of devising a free-piston engine/hydraulic pump which comprises all of the previously listed common technical features including those that have an effect on the achievement of the common technical result.

Based on the information presented above there is every reason to believe that the claimed inventions according to claims 1, 2 and 3 do not contain one or several of the same or corresponding special technical features since they do not define a contribution which each of the claimed inventions, considered as a whole, makes over the prior art. There is

therefore an a posteriori lack of unity of invention since all of the common technical features are known and/or clearly derivable from the prior art.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/UA 2022/000013

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REFERENCES CITED IN THE DESCRIPTION

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- WO 20012010 A **[0002]**
- UA 92483 **[0004]**

Non-patent literature cited in the description

- **P.A. SHELEST.** *Bezvalnyye generatory gasov,* 1960, 302-305 **[0003]**