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FREE-PISTON ENGINE WITH OPPOSITELY MOVING MASSES

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Fig. 1

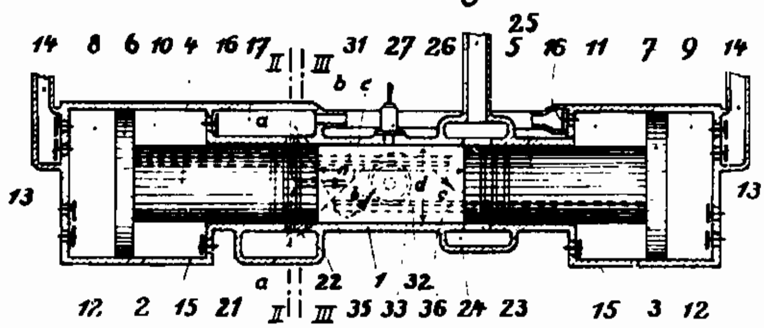


Fig. 2

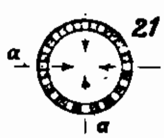


Fig. 3

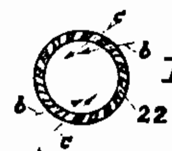


Fig. 4

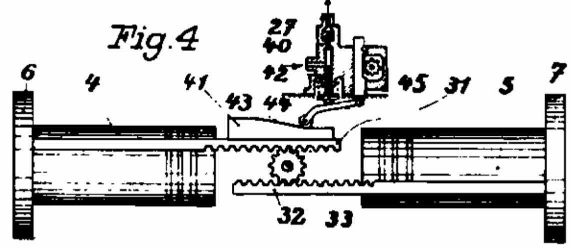


Fig. 5

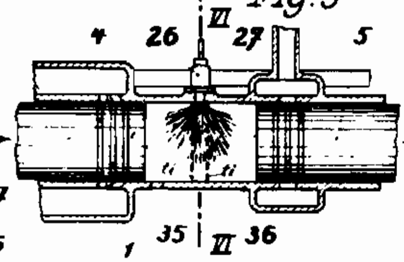


Fig. 6

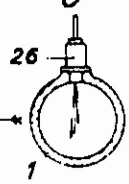
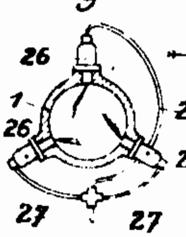


Fig. 7



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ALIEN PROPERTY CUSTODIAN

FREE-PISTON ENGINE WITH OPPOSITELY MOVING MASSES

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Free-piston engines having oppositely moving masses and a motor part working according to the two-stroke self-ignition or Diesel system are generally of elongated construction, because their length with a given arrangement and shape of the elements of the engine always equals a certain multiple of the stroke of the motor pistons and the ratio of the length of this stroke to the diameter of the motor cylinder must be ample when in the motor part favorable operating conditions (for instance, as to scavenging, fuel distribution, combustion &c) are aimed at. Furthermore a large stroke of the flying masses involves a relatively small number of strokes per unit of time, and therewith a low limit of efficiency.

As in free-piston engines the length of the stroke is not absolutely fixed, but is subject to certain variations, hereafter an unvariable and easily definable value shall be substituted therefor, that is the distance which the front faces of the motor pistons have from each other when the piston governing the exhaust outlet just opens or closes the outlet ports provided in the cylinder wall. This distance may be called "useful-space length", because it represents the length of the space which contains the motor cylinder charge which is subject to compression and therefore is "useful space".

It is true that free-piston engines of this kind have been described in which the ratio of length of the useful space to the diameter of the motor cylinder is relatively small (down to about $n:d=1.2$); in practice, however, a limit lower than 2.8 was not surpassed, because otherwise the operating conditions in the motor part would have become too unfavorable. For instance, it was ascertained that by decreasing the ratio of n:d the scavenging becomes incomplete inasmuch as exhaust gases remain in the motor cylinder so that only a correspondingly reduced quantity of fuel can be burnt, whereby the efficiency per unit of volume is reduced. Furthermore, as in a short-stroke engine in the inner dead position of the motor-pistons the distance of the piston bottoms from each other is smaller than in a long-stroke engine having the same useful space, in the short-stroke engines a greater part of the fuel to be injected will collect at the piston bottoms and thereby be excluded from the combustion. Therefore it was hitherto for practical reasons necessary to employ a high ratio of n:d and to put up with a relatively small number of strokes per unit of time for such engines.

It is true that one has proposed to make the working space of the motor annular instead of cylindrical in order to reduce the length of the useful space and therewith the total length of the engine. However this construction was not adopted in practice, above all for the reason that a motor having an annular working space is quite more difficult to construct than a cylindrical one; further drawbacks consist therein that with an annular working space it is more difficult to obtain an intimate contact of the combustion air with the fuel to be injected, and that the heat-radiating surface of the combustion space is considerably greater than with a full-cylindrical working space.

The object of my invention is to procure a short-stroke free-piston engine having flying masses moving in opposite directions and a simple, full-cylindrical working space of the motor part, but affording favorable operating conditions similar to those of a long-stroke engine.

I have discovered that the practical difficulties hitherto observed in connection with a short-stroke free-piston engine provided with compression ignition and full-cylindrical working space are substantially attributable to the fact that short stroke involves a lower utilization of the air or the oxygen of the air introduced during the scavenging operation into the working space of the motor for the combustion of the fuel. This lowered utilization is characterized on the one hand by a diminished scavenging effect, inasmuch as a relatively great amount of exhaust gases and a correspondingly reduced amount of air remain in the motor working space, and on the other hand by an increase of the excess of combustion air, as a greater portion of the air left behind in the motor working space not participates in the combustion step.

Means are well known (or have been proposed) to increase the utilization of the air supplied to the motor working space during the scavenging operation for the combustion of fuel. For instance, it is old to improve the scavenging quality in crank motors by arranging the ports provided in the wall of the working cylinder in such a manner that the passing jets of scavenging air flow in different directions, part of the jets being radially directed so that these jets meet near the cylinder axis and then united continue flowing in the middle of the cylinder thereby scavenging the core of waste gas, whereas the other jets of scavenging air flow more tangentially and are in certain cases more or less inclined toward the cylinder axis, thereby producing a helical whirling flow surrounding the central flow. With this kind of scavenging—in contradistinction to the usual pure whirly scavenging which with short-stroke motors as proved by experiments results in a bad core scavenging—even with short-stroke engines complete scavenging of the waste gasses is obtained. At the same time the advantage of the pure whirl-scavenging is preserved, to wit the production of an air circulation continuing during the compression and injection of fuel, whereby the contact of the air with the injected fuel is favored.

For free-piston engines with a motor part working with two-stroke and compression ignition one has proposed to supply at least a notable part of the fuel to be introduced already before the self-ignition temperature is reached, so that up to the moment of self-ignition a mixture of air and unburnt fuel is compressed. In this case a longer period for approaching the air to the fuel is available than with the usual injection taking place after the self-ignition temperature has been reached; moreover the danger of the greater part of the fuel to be injected getting to the bottoms of the pistons is avoided, because the latter have yet a considerable distance from each other. In this case it is even possible to arrange the supply of fuel to be adjusted so that the cloud of fuel particles formed of the injected atomized fuel extends in the direction of the cylinder axis at both sides and considerably beyond the dead space, and in this way to bring as far as possible the whole of the combustion air early (before the beginning of the compression) into intimate contact with the fuel. These measures therefore enable the excess of combustion air required for complete combustion to be diminished, i. e. to completely burn more fuel than heretofore with the same charge of air and thereby to correspondingly increase the effect of the machine.

Furthermore it is favorable for the diminution of the excess of air to introduce the fuel into the air charge at different points distributed, in the well known manner, over the combustion space.

Correspondingly the inventor proposes to use short strokes in the motor part of a free piston engine, working according to the two-stroke self-ignition (Diesel) system and having the usual full-cylindrical working space, i. e. to construct the motor part in such a manner that the ratio of the "useful-space length" to the diameter is about equal to or less than 2, and at the same time to provide means of the above-mentioned kind which permit of a better utilization of the air, introduced into the working space of the motor during the scavenging operation, for the combustion of fuel. Such means may be employed either singly or in combination with one another.

In this way the motor part of the free-piston engine operates under similar favorable conditions as that of a long-stroke engine. Moreover it affords, as compared with the latter the advantage of a reduced length and a higher efficiency due to the higher number of strokes.

The invention will now be more fully explained at the hand of the annexed drawings of which

Fig. 1 is a longitudinal central cross-section of a free-piston engine, the oppositely moving flying masses of the engine being in the position in which the motor piston controlling the air outlet ports provided in the wall of the motor cylinder just opens or closes;

Figs. 2 and 3 show cross-sections through the fresh gas inlet ports on the lines II—II and III—III of Fig. 1 respectively;

Fig. 4 shows in side elevation the flying masses of the engine together with their coupling gearing in the same position as in Fig. 1, and the fuel pump together with its drive in cross-section;

Fig. 5 is a cross-sectional view of the motor part of the engine during the inward stroke of the motor pistons.

Fig. 6 is a cross-section of the dead space on the line VI—VI of Fig. 5 and

Fig. 7 shows a similar cross-section with the arrangement of a plurality of injection nozzles.

The engine shown in Fig. 1 comprises a motor cylinder **1** and compression cylinders **2**, **3** joined with its ends. In the motor cylinder do operate the motor pistons **4**, **5**, in the compression cylinders the compression pistons **6**, **7**, the latter dividing the compression cylinders **2**, **3** into the two compartments, viz. the outer compression compartments **8**, **9** and the compartments **10**, **11** turned toward the motor cylinder **1** and serving as scavenging pump in the present example. The compression compartments **8**, **9** are provided with suction valves **12** and non-return valves **13**, the latter being located in chambers to which are joined the pressure pipes **14** for conducting away the compressed gas. The scavenging pump compartments **10**, **11** are provided with suction valves **15** and non-return valves **16**. The latter allow the conveyed scavenging air to enter a scavenging air receiver **17** surrounding the motor cylinder. In the wall of the motor cylinder **1** at one side near the end of the working space scavenging ports **21**, **22** are provided which are arranged in two circumferential rows succeeding each other in axial direction and communicating directly with the receiver **17**. At the other side of the working space outlet ports **23** are provided in the wall of the motor cylinder near the other end of the working space, which ports communicate with a collecting space **24** to which the exhaust pipe **25** is joined. Liquid fuel is supplied to the motor cylinder through an injector nozzle **26** arranged on the dead space to which the liquid fuel is supplied under high pressure by means of an injection pump over the compression pipe **27**. The flying masses formed by the pistons **4** and **6** on the one hand and the pistons **5** and **7** on the other hand are connected by a coupling gear (shown in dotted lines) in such a manner that they always perform corresponding opposite movements. For this purpose racks **31** and **32** are connected with each of the flying masses respectively. These racks engage at diametrically opposed points a pinion **33** journaled on a trunnion fixed in the motor cylinder frame. In the example shown the dimensions of the engine are chosen in such a manner that in the shown position of the pistons in which the motor piston **5** controlling the exhaust just opens or closes the outlet ports **23**, the distance n between the front faces **35**, **38** of the pistons (the "useful space length") is equal to the double diameter d of the motor cylinder, the ratio being

$$n:d=2$$

Now, in order to obtain the best possible utilization of the combustion air supplied to the motor cylinder for scavenging, in spite of this extraordinarily small ratio unfavorable to the self-ignition method with the usual configuration of the motor part, the fresh gas inlet ports are shaped in an especial manner. As already mentioned, two circumferential rows of such scavenging ports are arranged to succeed each other in axial direction. The ports **21** of the circumferential row which is more remote from the combustion space are formed in such a manner that the air jets passing through in the scavenging operation are vertically directed to the cylinder axis. These air jets (arrows *a*) impinge upon one another in the center of the cylinder and are then deflected toward the combustion space in the direction of the cylinder axis so that they transverse substantially the central portion of the cylinder, thereby shifting the core of waste gases outwardly. The ports **22** of the other circumferential row which is nearer to the combustion space are formed in such a manner that the passing air jets, as shown in Fig. 3, are directed more tangentially; furthermore these ports are inclined to the cylinder axis so that these air jets are simultaneously directed obliquely to the combustion space as shown by the arrows *b* and *c* (Fig. 1). This oblique direction differs in the single ports; for instance, ports of weaker inclination (arrow *b*) may alternate with ports of stronger inclination (arrow *c*). The ports may also have more than two different degrees of inclination, the ports having the same inclination being preferably uniformly distributed over the periphery. Furthermore also several circumferential rows of ports may be provided (as known per se) which produce jets deviating from the radial direction and directed obliquely towards the combustion space in such a manner that this deviation from the radial direction and the obliqueness are the more increased the nearer the circumferential row comes to the combustion space. The air streaming in through this circumferential row or rows traverses the cylinder, as indicated by the prolonged arrows *b* and *c* in helical direction and produces a strong air whirl lasting even after the inlet ports have been closed by the working piston which whirl is favorable for approaching the air to the fuel to be introduced into the combustion space. By combining this whirling scavenging with the core scavenging a quite perfect scavenging of the waste gases out of the motor cylinder is obtained, in spite of the unfavorable ratio of $n:d$, and the motor cylinder is filled with fresh air, so that a greater quantity of fuel can be burnt than with the usual form of the scavenging ports which with this small ratio of $n:d$ would result in an incomplete scavenging because especially the core of waste gases would be only incompletely removed. By the combination of the small ratio of $n:d$ with the scavenging device producing a whirl of air and simultaneously warranting the scavenging of the core of waste gases the short-stroke free piston engine becomes, as regards the scavenging, wholly equivalent to the long-stroke engine.

Fig. 4 shows a fuel supplying device which enables at least a considerable part of the fuel burnt per each working stroke to be introduced into the working cylinder before the cylinder charge has attained the self-ignition temperature of the fuel. The pump **40** conveying the liquid fuel to the injection nozzle **26** is in the well known manner driven by a cam **41** rigidly connected with one of the racks (f. i. **31**) of the coupling gear **31** to **33**. Whereas this cam is usually so formed that it drives the pump piston **42** in a conveying stroke only when the motor pistons approach their inner dead position, that is when the air enclosed between them has already reached the self-ignition temperature of the fuel, in the instant case the cam is so formed that with full load of the engine the conveying stroke of the pump piston **42** is initiated early, for instance, already when the outlet ports **23** are closed by the motor piston **4**. For this purpose the sloping part **43** of the cam **41** on which runs the roll **44** of the swing-arm **45** driving the pump piston **42** is so formed that it just begins to lift the pump piston when the piston is in the abovesaid position. The inclination of the sloping part of the cam is so small that the injection is extended over a considerable part of the inward stroke of the piston. The ignition of the injected fuel takes place only after the self-ignition temperature is reached. This method of supplying fuel which with crank engines would be inadmissible because of the excessive ascent of pressure taking place therein, can be employed without scruple in free piston engines working with free swinging masses because the energy effecting the compression of the motor cylinder charge is limited as to amplitude so that with rapidly increasing resistance, provoked by the increase of the pressure duc to the combustion of the injected fuel, the energy is soon consumed, and because flying masses under this increasing pressure rapidly reverse their direction of motion, whereby the pressure is again rapidly decreased, so that an excessive increase of pressure cannot take place. On the other hand an advantage is attained inasmuch as now substantially more time is available for approaching the combustion air to the fuel than with the usual supply of the fuel taking place after the self-ignition temperature is reached, and consequently the combustion is a much more complete one, that is that more fuel can be completely burnt with the same air charge than heretofore. This injection method itself contributes to substantially increasing the utilization of the air charge for combustion which otherwise is bad in short-stroke free piston engines.

Especially advantageous is the combination of this method of fuel injection with the above described scavenging method (united whirl- and core scavenging).

The above-mentioned especial method of supplying fuel enables a further improvement in approaching the combustion air to the atomized fuel supplied into the combustion space. In the beginning of the fuel supply the front faces **35**, **36** of the motor pistons **4**, **5** are placed at a relatively great distance from each other. The fuel may therefore be introduced into the combustion space in such a manner that the cloud consisting of minute particles of fuel extends at both sides in the direction of the cylinder axis beyond the dead space, without risking that a considerable part of the injected fuel attains the bottoms of the pistons and then is incompletely burnt. Hereby the air space comprised between these bottoms, which is yet great at the beginning of the injection, is thoroughly interspersed with fuel, and the combustion air is perfectly approached to the fuel even if the usual whirl-scavenging is not employed.

An engine provided with a fuel injection of this kind is shown in Figs. 5 and 6. The fuel is here introduced into the working space of the motor by means of the nozzle **26** in the form of a fan, the plane of this fan extending in the direction of the axis of the working cylinder, and this fan extending at both sides far beyond the inner dead position of the front faces **35**, **36** of the pistons indicated by the dotted lines t_1, that is beyond the borders of the dead space, without incurring the risk of greater amounts of fuel adhering to the bottoms of the pistons.

With the usual, as well as with the described especial method of supplying fuel it is further advantageous to provide several supply points distributed over the combustion space. Fig. 7 shows by way of example three injection nozzles 27 uniformly distributed over the periphery of the dead space. The jets or fans of fuel may have in this case a direction deviating from the radial one, i. e. a more tangential direction in order to be as independent from one another as possible and to intersperse with fuel the air charge as uniformly as possible.

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