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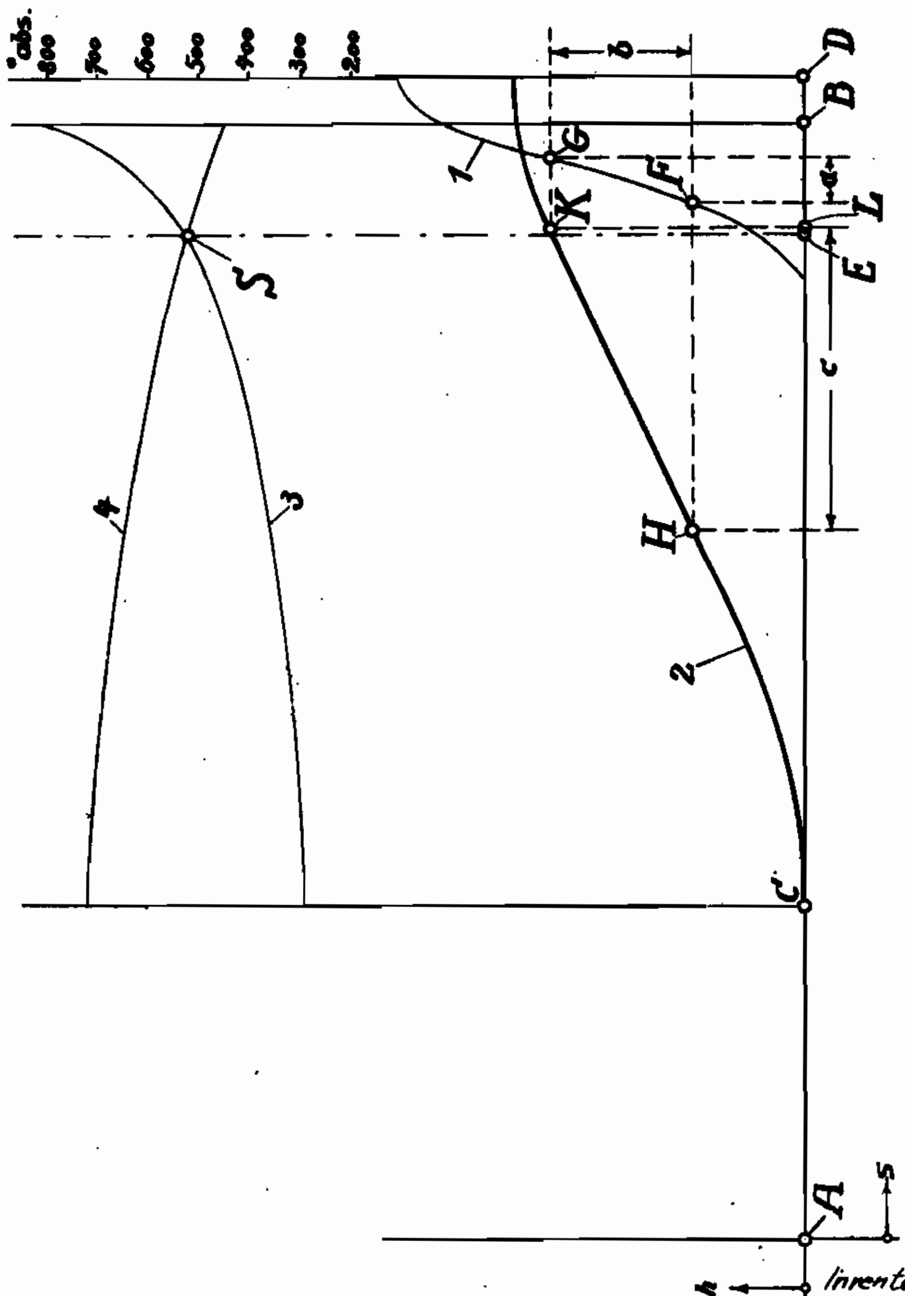

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METHOD OF OPERATING FREE-PISTON INTERNAL COMBUSTION ENGINES

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This invention relates to a method of operating free-piston internal combustion engines in which

1. the working space is scavenged with fresh air or charged before each compression stroke, the whole of the fresh air, enclosed in the working space after the fresh air inlets and the exhaust gas outlets have been closed, being available for the combustion step and being, immediately after this closure, compressed with continuously increasing pressure, and in which

2. the fuel, especially liquid fuel such as gas oil, is admitted to the working space of the motor apart from the combustion air and is exploded by means of compression ignition.

The principal object of the invention is to improve the combustion step taking place in the working space of the motor, in order to obtain a better utilization of the introduced fuel and, on the other hand to decrease to a considerable extent the formation of residues of combustion (oil coal or the like) in the working space, for instance, at the borders of the outlet openings. This is attained according to my invention by introducing into the working space either the whole of the fuel to be supplied per one cycle, or a considerable part of it during the compression stroke before the temperature of self-ignition is reached so as to form a fuel-air mixture and to further compress this mixture until it finally reaches the ignition-temperature and is burnt. The fuel may be supplied already during the closure of the outlets. When operating according to the invention a relatively long period is available for mixing the combustion air with the fuel so that the conditions for obtaining a complete mixture and therewith a combustion as complete as possible are more favorable than, for instance, with the normal Diesel system in which the whole of the fuel is supplied to the combustion chamber only after the temperature of self-ignition is reached and therefore the intimate mixture of fuel and air required for the combustion can be obtained only with greater difficulty.

The operating method according to the invention will now be more fully explained at the hand of the annexed diagram.

In this diagram on the horizontal axis the displacement s of the motor piston is cut off. The line A—B corresponds to the stroke of the motor piston, A representing the outer, B the inner dead point. Point C denotes the beginning of the compression (closure of the outlet openings of the working space of the motor). Line B—D corresponds to the noxious space. Above the horizontal axis four curves 1 to 4 are drawn. The curves 1 and 2 show the displacement h of the piston of the injection pump, to wit curve 1 relates to the Diesel system as hitherto used in free-piston internal combustion engines, whereas curve 2 is for an example of the operating method according to the invention. Curve 3 shows the course of the compression temperature of the air enclosed in the working space of the motor. Curve 4 represents the course of the ignition-temperature for a certain fuel, for instance, gas oil (one of the fractions obtained by distilling petroleum, having a specific gravity of about 0.865), this ignition-temperature being known to decrease with increasing compression of the air surrounding a particle of fuel. The temperature of self-ignition of the employed fuel is determined by the point of intersection S of the two curves 3, 4. In the present example it amounts to 520° abs.

Point E on the horizontal axis corresponds to point S; this point E must have been reached by the working piston of the motor on its compression stroke in order that the self-ignition temperature of the fuel be reached by the compression of the combustion air performed till then. In the normal Diesel system as usually employed hitherto the whole of the fuel required for each working stroke is injected into the working space of the engine only after the self-ignition temperature is reached. The injection begins in this case a short distance behind the point E at a point corresponding to the point F of the curve 1 denoting the displacement of the piston of the injection pump, and lasts up to point G of this curve. It extends therefore only over the short way a (horizontal distance of the points F, G) of the working motor piston and accordingly lasts only for a very short period. The injected amount is represented in this case by the line b (the vertical distance of points F, G).

When operating in accordance with the invention the injection of the fuel begins already at a considerable distance from the point E, to wit in point H of the curve of displacement 2; it ends in point K of the same which in the example shown lies a short distance behind point E. The injection therefore extends over the distance c between the points H, K which is considerably greater than the distance a and also involves a longer injection period. Nevertheless the amount of the injected fuel is the same as in the former case, to wit the amount indicated by line b.

If in a common internal combustion engine having its piston forcibly attached to a crank shaft the fuel were supplied in this way, i. e. if the whole of the fuel were supplied during the compression stroke before the self-ignition temperature would be reached, the whole charge of fuel would be suddenly exploded at the self-ignition point E of the travel of the piston, i. e. at a considerable distance from the inner dead point B. A pure equal-space combustion would result which, as we know, in itself is connected with a very steep ascent of pressure. Because, however, the motor piston under the action of the crank shaft is further driven inwardly beyond the inner dead point, the ascent of pressure is hereby still further increased to a considerable extent and the working space and the gearing are subjected to extraordinary stresses; hereby especially unfavorable dynamic stresses in the elastic parts of the gearing are produced. As furthermore in an engine of this kind the working piston would stay for a relatively long time near the inner dead point, the wall of the combustion space would be exposed for a long time to the excessively high temperature of the combustion gases which, owing to the dissipation of heat increasing with the pressure, would involve a considerable loss of energy and an excessive impairment of the constructional materials.

Quite other conditions prevail in connection with internal combustion engines having free pistons in which the inner dead point is not forcibly determined by a gearing. On the contrary, the flying mass may turn back when the energy with which it is projected toward the inner dead point has been consumed by the compression work to be done on this stroke. The flying mass is therefore not retained for a longer time in the proximity of the inner dead point, but undergoes a vehement retardation on the inward stroke owing to the sudden increase of pressure caused by the combustion, whereby it is rapidly stopped, and this retardation is followed by a vehement acceleration whereby a rapid motion in the reverse direction is effected. Thus the drawbacks appearing in connection with crank shaft engines do not exist with free piston engines. This fact was ascertained by experiments.

Besides the advantages of the new operating method already referred to the following advantage is to be noted: The forces of masses acting on the piston of the injection pump which, when excessive, would interfere with the course of the injection are essentially lower than in the normal Diesel system which appears at once from the more flat course of the displacement curve 2 as compared with the much steeper curve 1. In this connection it may be noted that the diagram in which the beginning of the displacement of the pump piston approximately coincides with the beginning (point C) of the compression does not even represent the most favorable case. On the contrary, it is especially advantageous to begin with the supply of fuel already during the closure of the outlet openings. In this case the beginning of the supply (point H) would lie considerably farther to the left (even on the left side of point C), whereas the end of the supply (point K) may retain its position. The curve 2 would then show a much flatter course. By such a course of the injection, moreover, abundant time for mixing air and fuel is available whereby the mixing is considerably promoted.

The part H—K of the curve 2 which is illustrative of the supply of fuel may also be shifted as a whole from the position shown in the diagram to the right so that merely a notable part of the quantity of fuel to be supplied, at least about 30 p. Ct. is supplied to the working space of the motor before the self-ignition temperature has been reached. Hereby also an essential improvement of the combustion step over the normal Diesel system is attained.

It has proved especially advantageous by virtue of experiments to position the point K of the curve 2 (indicating the end of the fuel supply) or the corresponding point L on the horizontal axis in such a manner that the ratio of the line L—D to line C—D (the ratio of the compression volumes) is about 1:5.5.

The described advantages of the invention are also obtained if only a considerable part of the amount of fuel required for each working cycle is introduced into the working space of the motor, before the temperature of self-ignition is reached, and the resulting mixture is further compressed up to self-ignition, the remainder of the fuel being supplied only after the ignition of the first-mentioned fractional amount. This enables the degree of the ascent of pressure produced by the combustion to be influenced and a too abrupt initiation of the combustion to be avoided.

A further advantage of the method according to the invention over the usual Diesel system was ascertained, viz. that the invention requires a considerably smaller amount of scavenging air because owing to the longer period available for mixing air and fuel a smaller total amount of air suffices to bring the fractional amount of air required for the combustion of each single particle of fuel into contact with this particle. The power for supplying the scavenging air is correspondingly reduced.

On the other hand with unreduced supply of scavenging air it is possible to temporarily overload the free piston engine to a considerable extent, because even with increased supply of fuel sufficient air is present to warrant complete combustion of the mixture.

The displacement curve 2 corresponds—in the case of supplying the fuel by means of a pump—to the shape of the cam driving the piston of the pump which cam is rigidly connected with a member participating in the displacement of the motor piston.

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