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GB 1033851
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GB 804723
GB 636080
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(54) **An air-compression direct-injection internal combustion engine**

(57) An air-compression, direct-injection internal combustion engine comprises a radially-symmetrical air swirl combustion chamber (3) arranged in a piston (1) or cylinder head (8), and a multi-hole fuel injector (7) for injecting liquid fuel into the combustion chamber (3) in the direction of the air swirl and being off-set with respect to the longitudinal axis of the combustion chamber, the fuel injector (7) having a needle valve 18 which uncovers a first nozzle hole or holes (21) at low engine speeds and/or loads and a second nozzle hole or holes (24) at higher engine speeds and/or loads the ratio (δ) of the maximum combustion chamber diameter (D) to the diameter (d) of the said throad (4) being between 1.05 and 1.25, and the rotary frequency (fl) of the rotating air (16) — referred to the measuring diameter (0.7 times cylinder diameter) and at maximum valve lift as well as 10 m/sec mean piston speed — being between 135 and 185 Hz, and the injection cycle — referred to full load at the smoke limit — at a mean piston velocity (cm) of 10 m/sec extending over more than or at least 20° crank angle. A double needle injector may be used.

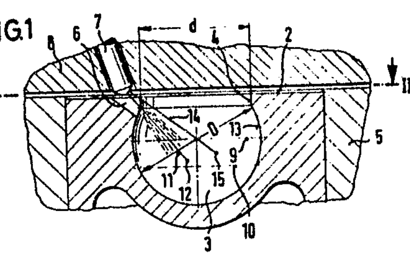
FIG1


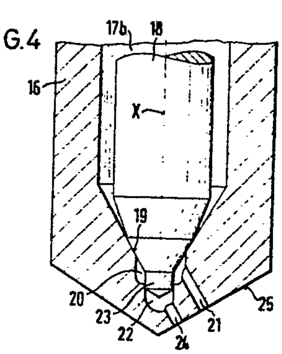
FIG.4


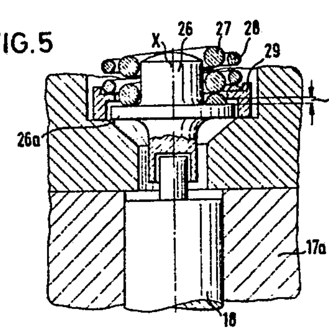
FIG.5


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FIG.1

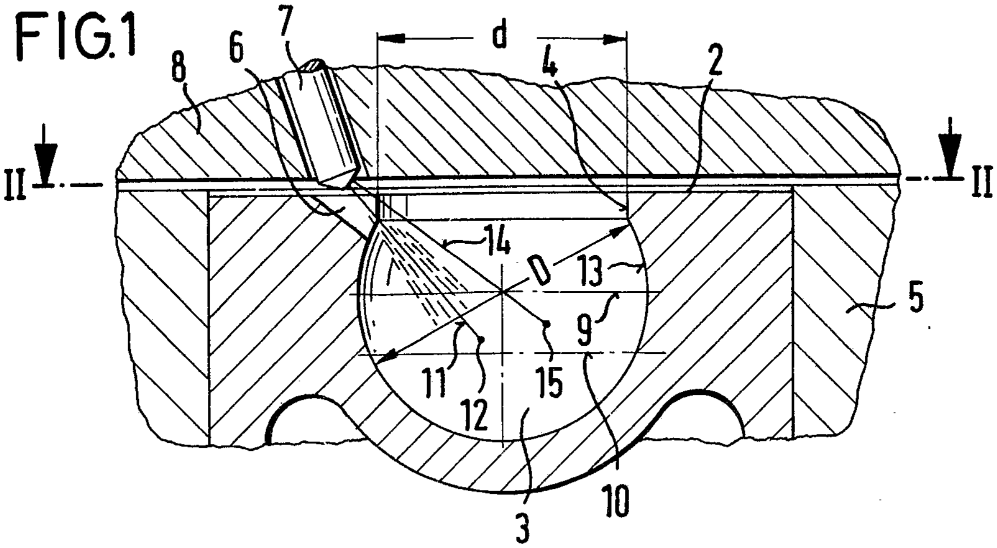


FIG.2

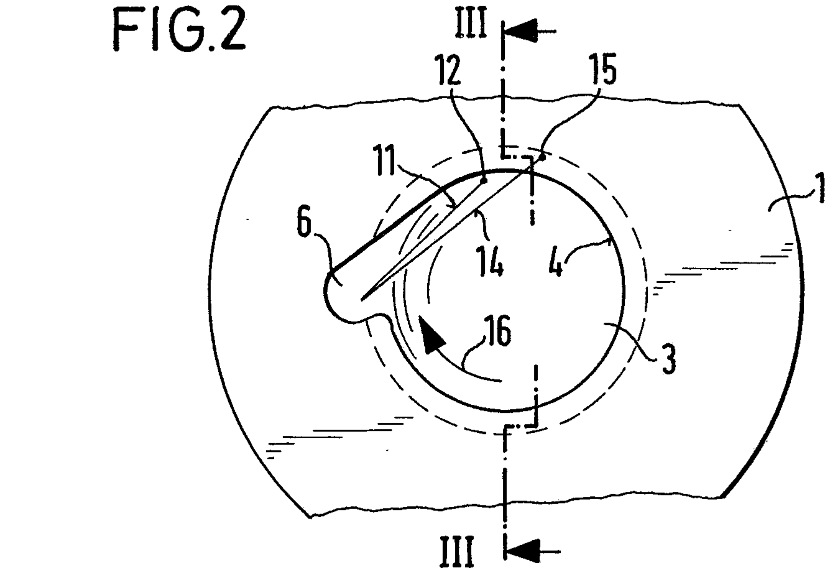


FIG.3

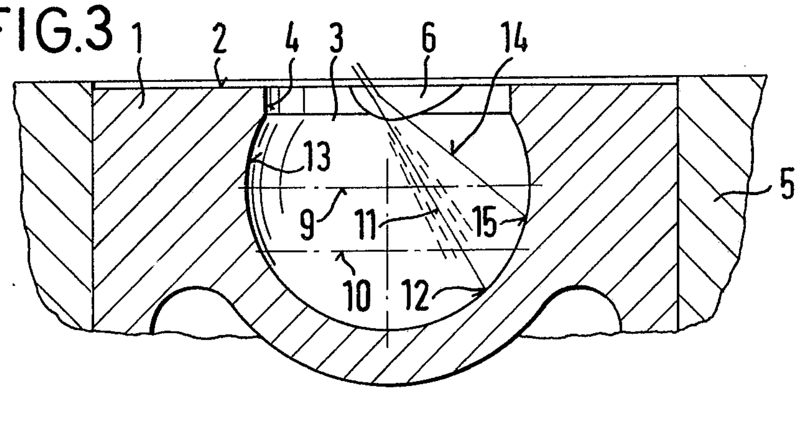


FIG. 5

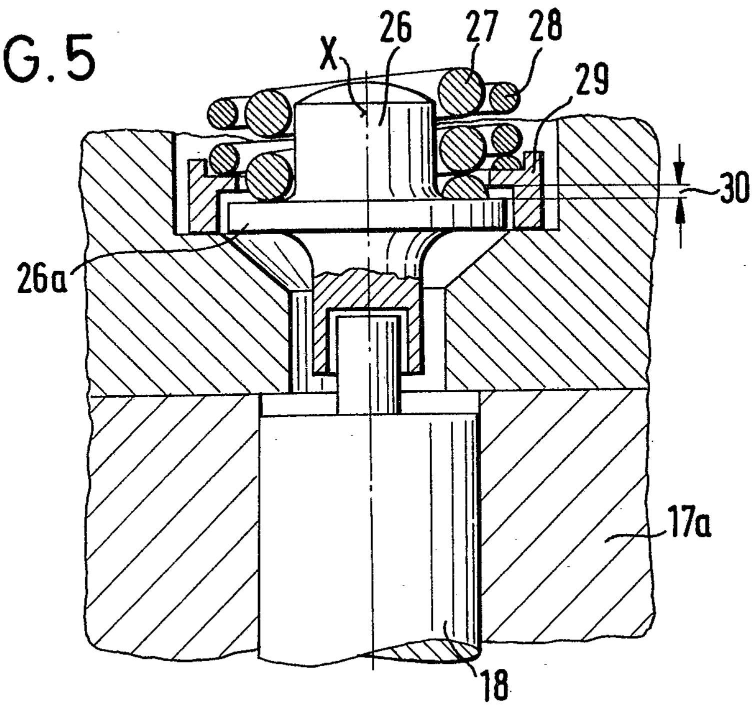


FIG. 4

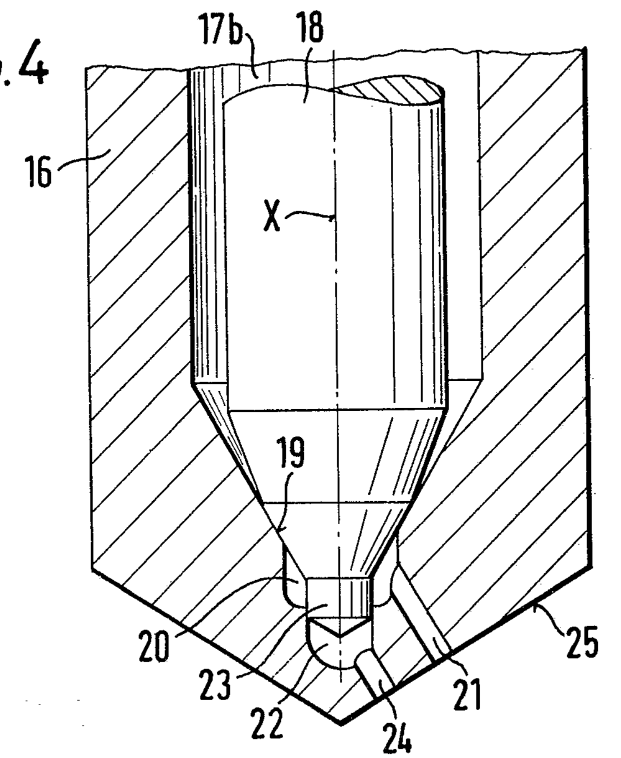


FIG.6

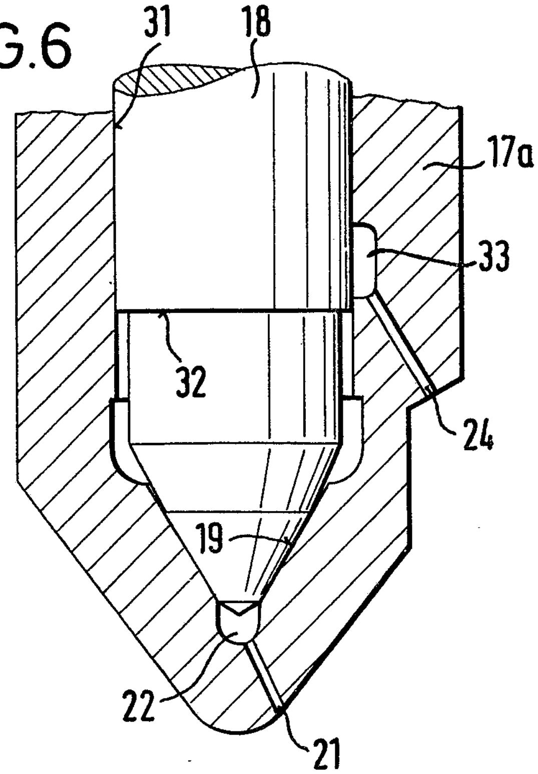
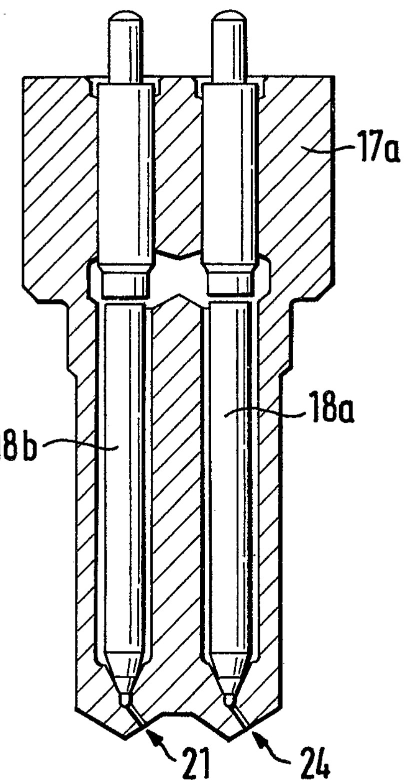


FIG.7



SPECIFICATION

An air-compression direct-injection internal combustion engine

This invention relates to an air-compression direct-injection internal combustion engine comprising a radially-symmetrical combustion chamber arranged in a piston or cylinder head, and having a constricted throat relative to the maximum diameter of the combustion chamber, means for forming a rotary air swirl about the longitudinal axis of the combustion chamber and a multi-hole fuel injector for injecting liquid fuel into the combustion chamber in the direction of the air swirl and being off-set with respect to the longitudinal axis of the combustion chamber and being controlled as a function of the load and speed of the engine so that in use a fuel film is formed on the combustion chamber wall.

An internal combustion engine of this type has been disclosed in the German patent specification 865 683. According to that disclosure, the fuel is applied to the wall of the combustion chamber with as short as possible a trajectory in order to limit direct mixing of the fuel with the air to a minimum, as is required for ignition. The points of impingement of the fuel jets are therefore on the upper half of the combustion chamber wall.

It was soon found that such a method of injection gives rise to an environmental problem with blue smoke forming at idling and at lower and medium loads of the engine leading to irritation of the eyes and respiratory organs. The blue smoke is formed because the temperature of the combustion chamber wall is too low for efficient combustion. Poor combustion promotes the formation of aldehydes, acrelein, certain hydrocarbons and other substances in the exhaust gases.

In order to overcome this problem, it has been proposed in German patent publication 1 020 210 partly or wholly to destroy or eliminate the air swirl in the operating ranges referred to, or even to change the direction of the fuel jets in a manner so as to increase the proportion of fuel mixing directly with the air. Furthermore, it has been proposed to raise the compression ratio or to extend the fuel injection period at lower speeds in order to prevent the formation of slug-type fuel jets and to ensure a greater proportion of direct fuel-air mixing.

While such measures enabled an appropriate decrease in blue smoke and irritants in the exhaust gases to be achieved, they have been unsatisfactory inasmuch as the additional means required involved increased costs and at the same time increased vulnerability, or tended to penalize engine performance at upper loads, especially at full load.

German patent specification 2 038 048 discloses a spherical combustion chamber in which the ratio of the combustion chamber diameter and its opening diameter is limited to a defined value and the point of impingement of the one fuel jet provided is relocated into the lower quarter of the combustion chamber wall, the ratio of the air charge revolving in the peripheral direction to the axial velocity of the piston being defined. The purpose of these measures is so that as great as possible a proportion of the injected fuel is mixed directly with the air for combustion, and as small as possible a proportion of the injected fuel is deposited as a film on the relatively cold wall of the combustion chamber during the operating phases referred to. One feature, namely the fuel jet orientation is, however, no longer defined where the spherical combustion chamber is abandoned in favour of another combustion chamber in the shape of a solid revolution.

An object of the present invention is to provide an internal combustion engine of the type initially described in which an optimum reduction of blue smoke and white smoke formation is achieved when operating at idling and in lower and medium part loads of the engine without increased costs and without an exact definition of the fuel jet positions as well as without any penalty on performance at upper loads, while affording wide freedom in choosing the shape of the combustion chamber.

The invention provides an air-compression, direct-injection internal combustion engine comprising a radially symmetrical combustion chamber arranged in a piston or cylinder head and having a constricted throat relative to the maximum diameter of the combustion chamber, means for forming a rotary air swirl about the longitudinal axis of the combustion chamber, a multi-hole fuel injector for injecting liquid fuel into the combustion chamber in the direction of the air swirl and being off-set with respect to the longitudinal axis of the combustion chamber and being controlled as a function of the load and speed of the engine so that in use a fuel film is formed on the combustion chamber wall, wherein the fuel injector has fuel control means which uncovers a first nozzle hole or holes at lower speeds and/or loads of the engine and a second nozzle hole or holes at upper speeds and or loads, the ratio (δ) of the maximum combustion chamber (D) to the diameter (d) of the said throat heing between 1.05 and 1.25, and the rotary frequency (fl) of the rotating air—referred to the measuring diameter (0.7 times cylinder diameter) and at maximum valve lift as well as 10 m/sec mean piston speed—is between 135 and 185 Hz, and the injection cycle—referred to full load at the smoke limit—at a mean piston velocity (cm) of 10 m/sec extends over more than or at least 20° crank angle.

In other words, a hole-type nozzle is also used for the injection of the fuel in which no difficulties of installation arise because the nozzle holes can be matched to almost any combustion chamber configuration. Moreover, coking of the nozzle holes is substantially avoided because the injection cycles are exactly separated from each other.

By injecting the fuel in two stages it is easily possible to achieve extensive or even complete direct fuel/air mixing at no-load as well as at lower and possibly medium loads of the engine so that the drawbacks which result from the still insufficiently heated combustion chamber wall, are obviated. At upper loads, however, the fuel is, as previously, applied predominantly in the form of a film on the combustion chamber wall where it evaporates, mixes with the rotating air, and eventually is burnt. Furthermore, the staged fuel injection offers an advantage in that an improvement of combustion is also possible at full-loads and at low speeds, when black smoke formation and fuel consumption are reduced, as well as at higher speeds when lower ignition pressures and fuel consumption result, for instance under conditions of supercharging, by having an analogous manner only part of the nozzle holes uncovered at lower speeds whereas the full injection area is uncovered at higher speeds.

With a view to obtaining good engine performance in all operating ranges it is also necessary in conjunction with the two-stage fuel injection in order to accurately match up the air swirl to determine the optimum ratio of the maximum combustion chamber diameter to the diameter of its throat and the swirling speed. Finally, it is necessary to coordinate the fuel injection cycle period with the air swirl in order to optimize mixture formation.

The opening ratio between the maximum combustion chamber diameter to its throat is mainly dependent on the location and distribution of cross sectional area of at least two nozzle holes with the swirling speed of the air being selected to suit requirements in respect of speed, efficiency, torque and possible supercharging of the internal combustion engine. With the aforementioned parameters defined the choice of fuel jet orientations, especially with respect to the combustion chamber axis, is no longer as limited as previously. A wider band of variation is now possible. The essential requirement is only that the first fuel jet should not be directed at a point above the combustion chamber or rise out of it during the injection cycle and that the bottommost jet should not reach the bottom of the combustion chamber.

At full-load of the engine, when all nozzle holes are uncovered, at least one fuel jet should impinge near the equator or a short distance below it on the combustion chamber wall and this will obviously be governed by the shape of the combustion chamber, whether spherical, ellipsoidal or of a similar shape as well as by the nozzle outlet shape. This fuel jet or jets should at least contain half of the complete amount of injected fuel and be tangential to the combustion chamber wall in the circumferential direction of the air swirl and form the known film on it, whereas the other fuel jet or jets containing not more than half of the amount of injected fuel may, depending on the specific conditions, deviate from the swirl direction and, consequently, from the tangential position relative to the wall in order to produce the desired effect of an enhanced degree of direct mixing with the air at part load.

It has been discovered that the use of one of a number of particular injectors is most advantageous because in spite of excellent functioning they are of straightforward design and easy to instal in the cylinder head and because the nozzle holes can be readily provided to suit specific conditions prevailing.

In a preferred embodiment, the fuel control means comprises a nozzle needle axially-slidable in a nozzle body and biassed by at least one spring against a valve seat, said first nozzle hole or holes communicating with an annular space below the valve seat, and the said second nozzle hole or holes communicating with a blind hole provided below the annular space, a pintle formed as an extension of the nozzle needle being slidable into said blind hole to close the said second hole or holes.

At lower speeds and loads, the nozzle needle is lifted off its valve seat by only a slight proportion against a spring so that partial fuel injection occurs through the nozzle hole or holes communicating with the annular cavity. As the engine speed and load rises, the pressure in the fuel pipe and, consequently, in the annular cavity will also increase, the nozzle needle being further lifted against a second spring until the cylindrical pintle formed on it uncovers the blind-ended hole and eventually admits fuel into the nozzle hole or holes communicating with the blind-end hole. As a result, the full injection cross-sectional area will be available. The full injection cross-sectional area of all nozzle holes corresponds to the flow which, if a single-hole nozzle was used, the one nozzle hole would have and it should be mentioned that the allocation of area to the individual nozzle holes may be arbitrary, i.e. one nozzle hole or several nozzle holes may have larger and the other smaller cross-sectional area. In this manner, it is made possible at lower speeds and/or loads of the engine described that a sufficiently high line pressure can build up due to the increased throttling effect in order to uncover the appropriate injection cross-sectional area in the first stage of the needle lift. Thus an otherwise unattainable fuel atomization is obtained which, assisted by a wider band of fuel jet orientations, can have a more pronounced fuel-to-air distribution characteristic and, thereby, prevent intensive wall deposition of the fuel without preventing the desired wall deposition of the fuel at full load at medium and upper speeds, i.e. under conditions of increasing swirling speed and consequently centrifugal force of the air swirl and with the main fuel jet or jets delivering the fuel in a direction tangential to the wall under these conditions.

Embodiments according to the invention will now be described with reference to the accompanying drawings, wherein:

Fig. 1 is a longitudinal section through the upper part of a piston arranged in a cylinder showing the fuel jet configuration according to the invention.

Fig. 2 is a top view of a piston taken along the line II—II of Fig. 1.

Fig. 3 is a section along the line III—III of Fig. 2.

Fig. 4 is a longitudinal section through the lower part of an injector.

Fig. 5 is a longitudinal section through part of the spring combination acting on the nozzle needle according to Fig. 4, and

Figs. 6 and 7 each show a longitudinal section through the lower part of other injectors.

In Figs. 1 to 3, a combustion chamber 3 is formed in the piston crown 2 of a piston 1 (only the top of which is shown). The combustion chamber 3, which in this embodiment is spherical with a diameter *D* but may have any other shape of radial symmetry, communicates through a constricted throat 4 having a diameter *d* with the interior of a cylinder 5. A recess 6 in the throat 4 serves to admit the fuel injected by an injector 7 which is arranged obliquely in a cylinder head 8. The ratio of the combustion chamber diameter *D* to the diameter *d* of the throat 4 is designated the opening ratio and has a value of $1.05 \leqslant \delta \leqslant 1.25$.

The equatorial plane of the combustion chamber 3 is indicated by a dash-dot line 9, and the median of the lower part of the combustion chamber 3 is indicated by another dash-dot line 10. The lines 11 and 14 indicate the directions of two geometric fuel jets according to the invention which impinge on the combustion chamber wall 13 at point 15 and theoretically also along the extended axis at point 12. The impingement point 15 is located somewhat below the equatorial plane 9, whereas at lower speeds and partial load of the engine, the pilot jet 11 is atomized and broken up to an extent that it fails to reach the combustion chamber wall 13 and burns up before close to the wall. However, at higher speeds and loads, the higher rotary speed of an air swirl 16 causes the jet 11 to impinge by centrifugal action against the wall where it forms a fuel film together with the main jet 14 at a point somewhat below the impingement point 15.

In Fig. 4, an injector has a body 17*a* which has a hole 17*b* to accommodate a nozzle needle 18. The hole 17*b* tapers inwardly towards the bottom end and the sloping surface so obtained forms a valve seat 19 which the nozzle needle 18 contacts to form a seal in its position of rest.

Below the valve seat 19 is an annular space 20 which, in Fig. 4, communicates with a nozzle hole 21 disposed at an angle relative to the longitudinal axis *x* of the injector. Finally, the bore 17*b* terminates in a blind end hole 22 which, in the position of rest shown, is closed off by a cylindrical pintle 23 formed as an extension of the nozzle needle 18. From the blind end hole 22, another nozzle hole 24 extends through the nozzle body 17*a* to the outside and ends at a conical surface 25 of the body 17*a*.

In Fig. 5, the upper part of the nozzle needle 18 is axially-slidable in the nozzle body 17*a*. On the nozzle needle 18, there is a mushroom-shaped member 26 which is acted upon by one end of a spring 27, the other end of which bears against a holder (not shown). A holding spring 28, which has a larger diameter than the spring 27, acts upon a spring plate 29 which extends over a flange 26*a* of the mushroom-shaped member 26 and, in the direction of the longitudinal axis *x* of the injector is formed with a clearance 30 relative to the flange 26*a*.

As fuel is supplied to the injector, the nozzle needle 18 is first displaced axially against the force of the spring 27 until the clearance 30 is zero. As a result, the nozzle hole 21 becomes operative. At upper loads and/or at full load of the engine, the fuel pressure in the annular space 20 rises until it overcomes the force of the second spring 28, and the nozzle needle 18 opens to its maximum lift so that the pintle 23 uncovers the blind-end hole 22 and, thereby, the nozzle hole 24.

In Fig. 6, the nozzle body is again denoted by the numeral 17*a*, the nozzle needle by the numeral 18, the valve seat by the numeral 19, the blind-end hole by the numeral 22 and the nozzle holes by the numerals 21 and 24. At a point within the needle guide 31, the nozzle needle 18 is inwardly stepped to form a shoulder 32 serving as a control edge which, with the nozzle needle 18 fully open, uncovers a recess 33 in the nozzle body 17*a* which communicates with the nozzle hole 24 which is to be considered as the main nozzle hole. This embodiment differs from that shown in Fig. 4 mainly in that the so-called main nozzle hole 24 is further away from the nozzle tip than the nozzle hole 21 which is uncovered first.

Referring finally to Fig. 7, the control function is taken care of by two independent nozzle needles 18*a* and 18*b* arranged in parallel in the nozzle body 17*a* and serving two nozzle holes 21 and 24. The concept of part load injection at low speeds and full-load injection at higher speeds is identical.

CLAIMS

1. An air-compression, direct-injection internal combustion engine comprising a radially-symmetrical combustion chamber arranged in a piston or cylinder head, and having a constricted throat relative to the maximum diameter of the combustion chamber, means for forming a rotary air swirl about the longitudinal axis of the combustion chamber, a multi-hole fuel injector for injecting liquid fuel into the combustion chamber in the direction of the air swirl and being off-set with respect to the longitudinal axis of the combustion chamber and being controlled as a function of the load and speed of the engine so that in use a fuel film is formed on the combustion chamber wall, wherein the fuel injector has fuel control means which uncovers a first nozzle hole or holes at lower speeds and/or loads of the engine and a second nozzle hole or holes at upper speeds and/or loads, the ratio (δ) of the maximum combustion chamber diameter (D) to the diameter (d) of the said throat being between 1.05 and 1.25, and the rotary frequency (fl) of the rotating air—referred to the measuring diameter (07 times

cylinder diameter) and at maximum valve lift as well as 10 m/sec mean piston speed—is between 135 and 185 Hz, and the injection cycle—referred to full load at the smoke limit—at a mean piston velocity (cm) of 10 m/sec extends over more than or at least 20° crank angle.

2. An air-compression, direct-injection internal combustion engine as claimed in claim 2, wherein during opening of the nozzle needle against the bias of a first spring and after a certain partial lift of the nozzle needle, a second spring applies a bias in the same direction as the first spring.

3. An air-compression, direct-injection internal combustion engine as claimed in any one of claims 1 to 3, wherein the said second nozzle hole or holes are aligned so as to apply in use fuel tangentially on to the combustion chamber wall adjacent the combustion chamber equator in the direction of the air swirl the nozzle hole area delivering at least half the total amount of fuel injected.

4. An air-compression, direct-injection internal combustion engine as claimed in any one of the preceding claims, wherein the said first nozzle hole or holes is or are aligned so as to inject the fuel into the combustion chamber in a direction other than the direction of the air swirl, the nozzle hole area delivering not more than half of the total amount of fuel injected.

5. An air-compression, direct-injection internal combustion engine as claimed in any one of the preceding claims, wherein the fuel control means comprises a nozzle needle axially-slidable in a nozzle body and biassed by at least one spring against a valve seat, the said first nozzle hole or holes communicating with an annular space below the valve seat, and the said second nozzle hole or holes communicating with a blind hole provided below the annular space, a pintle formed as an extension of the nozzle needle being slidable into said blind hole to close the said second hole or holes.

6. An air-compression, direct-injection internal combustion engine as claimed in claim 1, 2, 3 or 4, wherein the fuel control means comprises a nozzle needle axially-slidable in a nozzle body and biassed by at least one spring against a valve seat, the said first nozzle hole or holes communicating with a blind-end hole at a level downstream of the valve seat, and the second nozzle hole or holes communicating with a recess in the nozzle body adjacent the nozzle needle such that after a predetermined nozzle-needle lift a control edge on the nozzle needle is aligned with the recess so as to admit fuel thereto.

7. An air-compression, direct-injection internal combustion engine as claimed in claims 1, 2, 3 or 4, wherein the fuel control means comprises two parallel nozzle needles axially slidable in a nozzle body and biassed by respective springs against respective valve seats, the arrangement being such that one of the nozzle needles is lifted off its valve seat at a lower fuel pressure, whereas the other nozzle needle is lifted off its valve seat only when the engine is running at upper speeds and/or loads.

8. An air-compression, direct-injection internal combustion engine substantially as herein described with reference to any one of the embodiments shown in the accompanying drawings.

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