June 2, 1942. C. R. ALDEN 2,284,627

NOZZLE

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Fig. 1

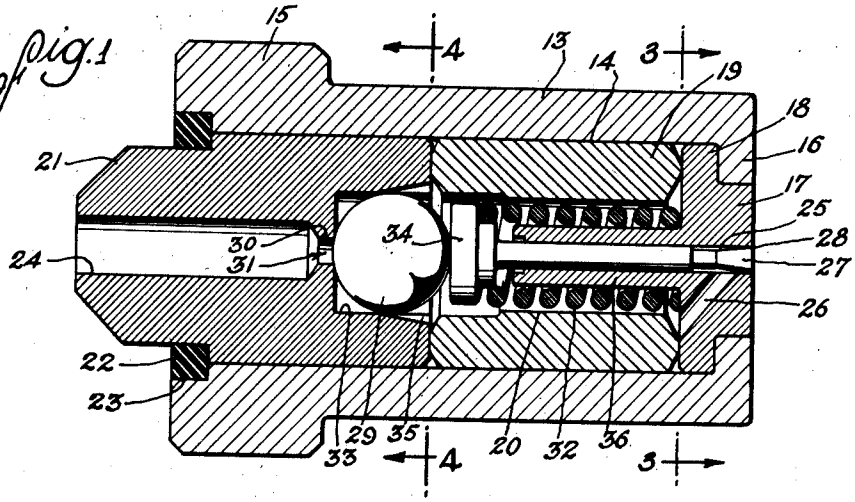


Fig. 3

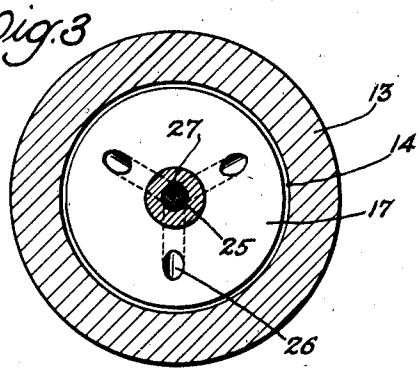


Fig. 2

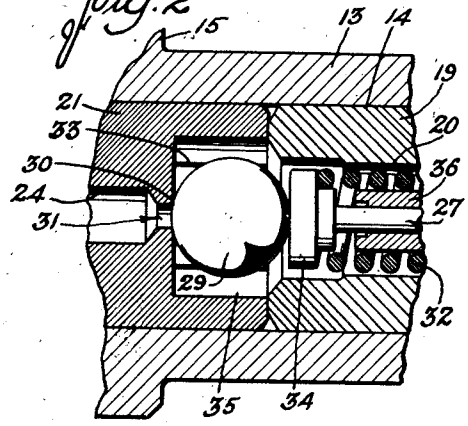
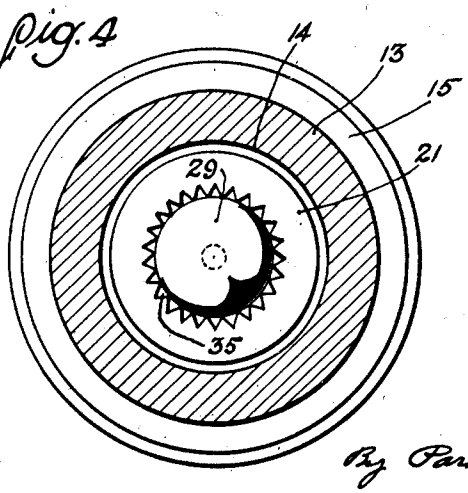


Fig. 4



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NOZZLE

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Fig. 5

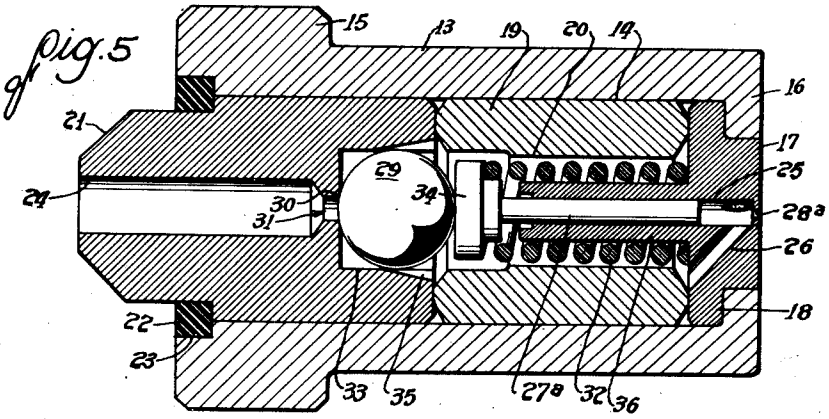
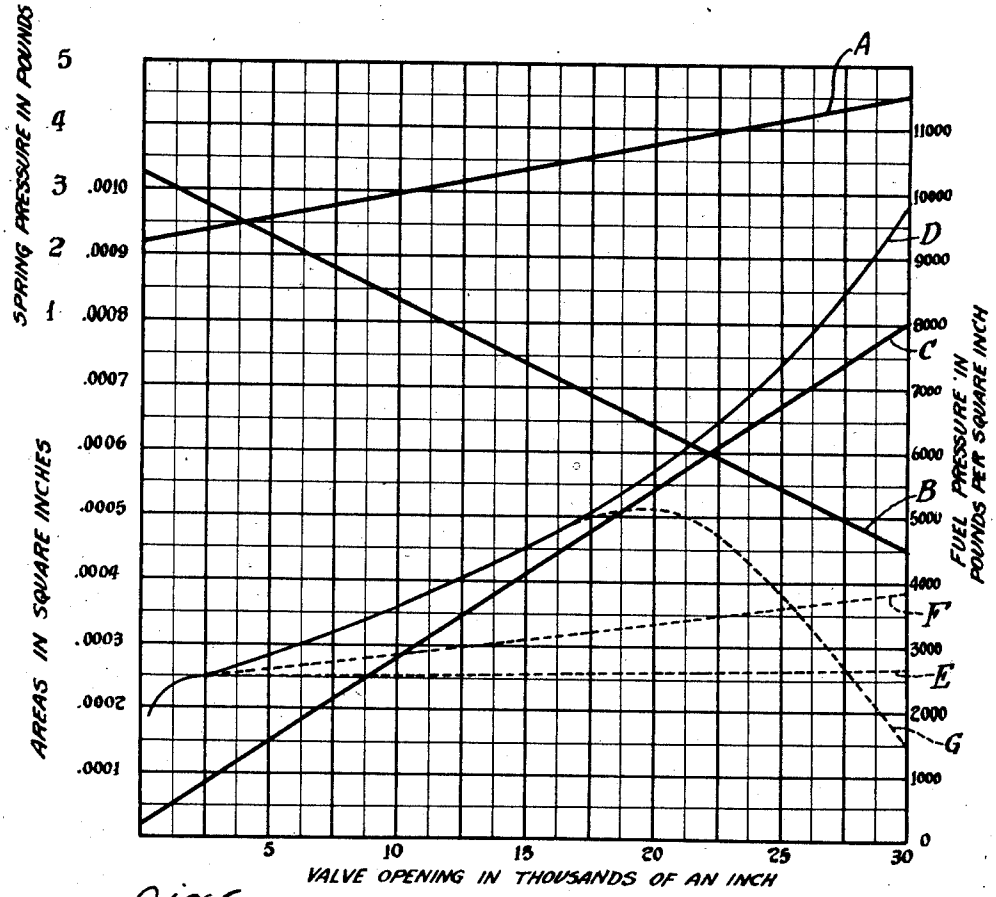


Fig. 6



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NOZZLE

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Fig. 7

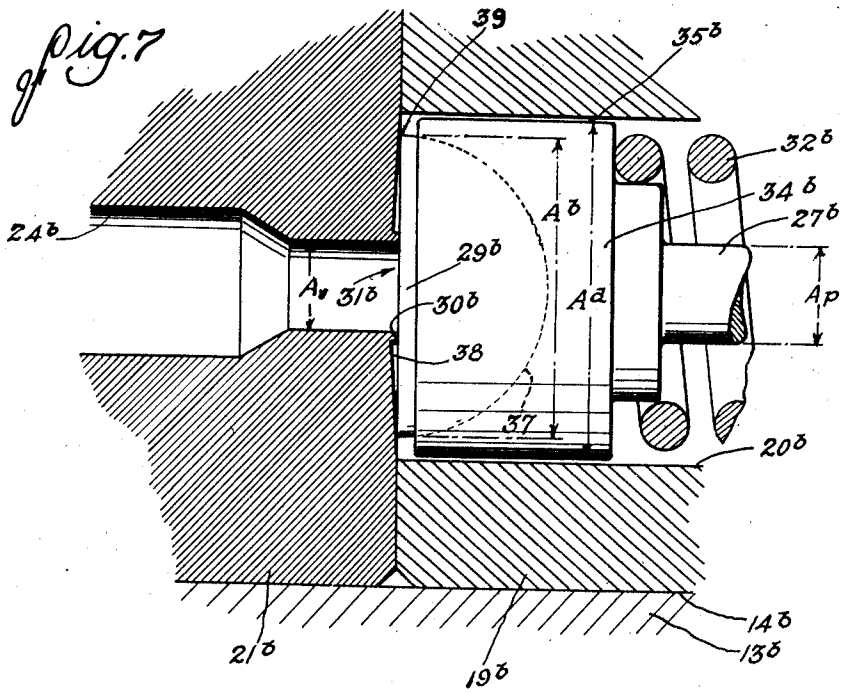
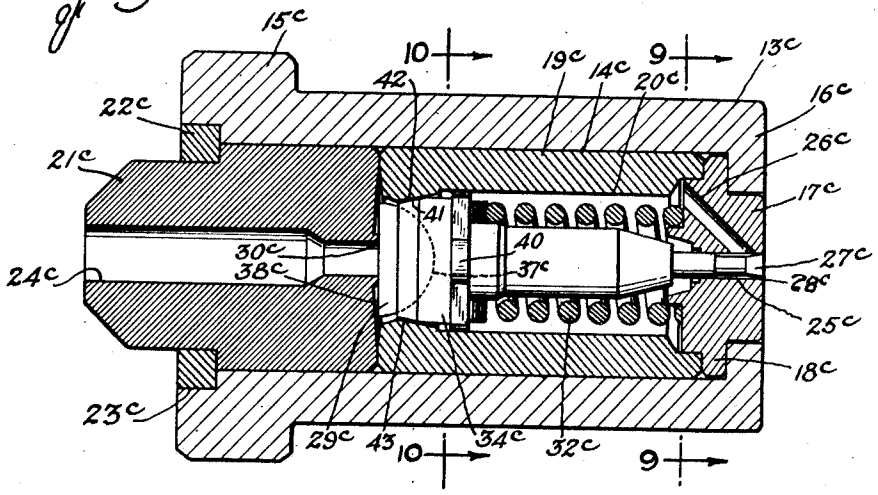


Fig. 8



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Fig. 9

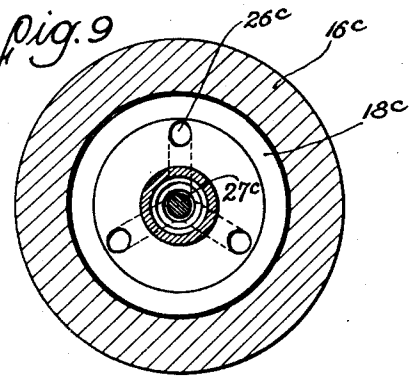


Fig. 10

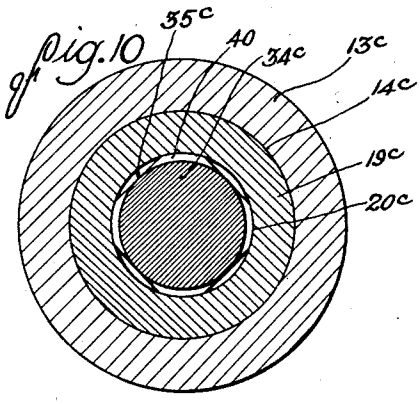


Fig. 11

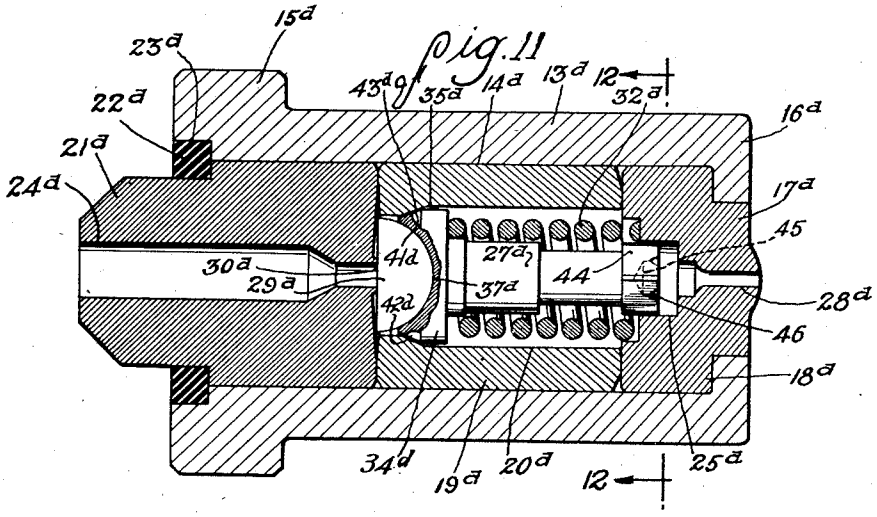
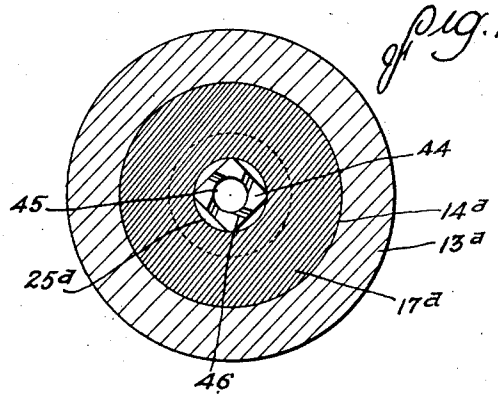


Fig. 12



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Fig. 13.

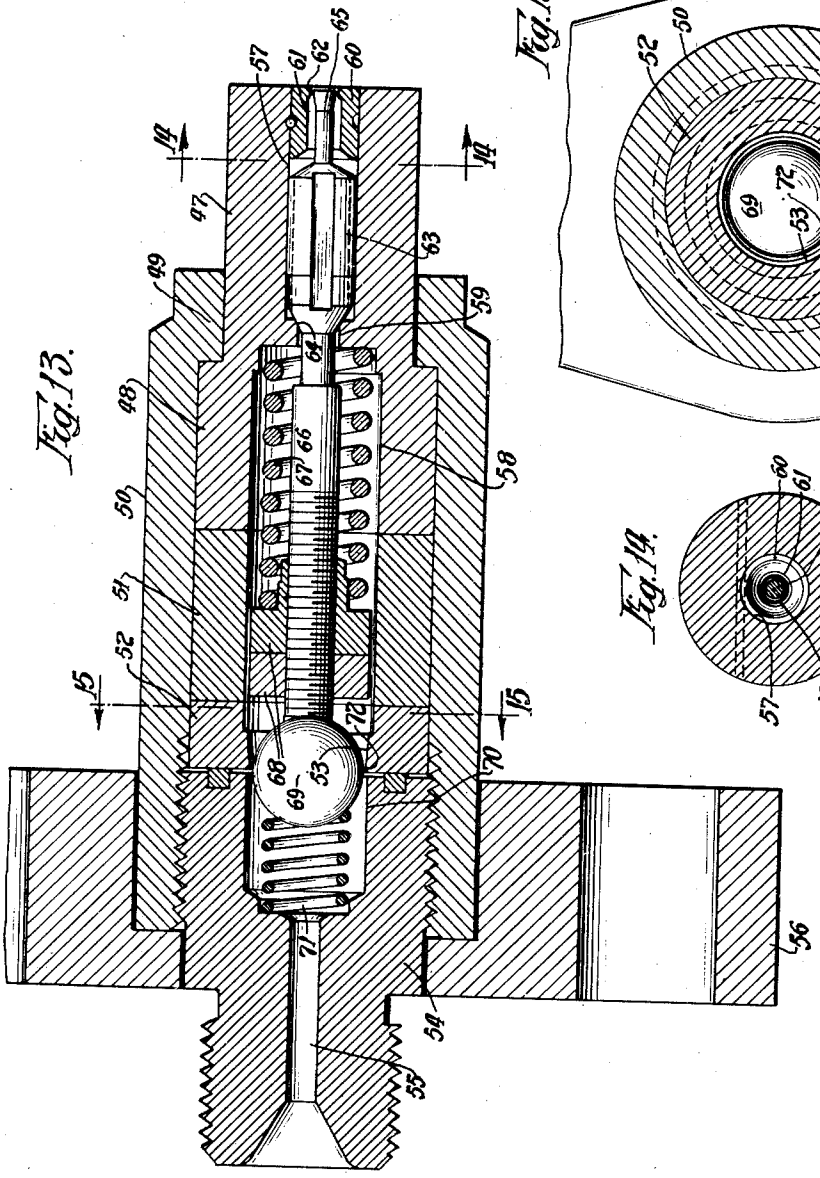


Fig. 15.

Fig. 14.

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UNITED STATES PATENT OFFICE

2,284,627

NOZZLE

Carroll R. Alden, Detroit, Mich., assignor to Ex-Cell-O Corporation, Detroit, Mich., a corporation of Michigan

Application July 6, 1937, Serial No. 152,074

21 Claims. (Cl. 299—107.6)

The present invention relates to improvements in nozzles adapted particularly for delivering timed metered injections of liquid fuel in connection with the operation of internal combustion engines.

In internal combustion engines with fuel injection, proper atomization of the fuel issuing from the injection nozzle is necessary to obtain a sufficiently intimate mixture with the air charge for efficient combustion. The fuel is usually finely dispersed in the form of a spray which may be varied to obtain different desired penetration and dispersion characteristics. To obtain proper atomization of the fuel, not merely during the intermediate portion of the injection period, but also at the start and end point of injection, a considerable fuel pressure should be required to open the injection valve so that an injection pressure sufficiently high for good atomization is immediately available, also the valve should open suddenly or rapidly to the extent of opening necessary for the required rate of injection, and lastly the valve should close suddenly or sharply at the end of injection to prevent dribbling, dripping or bleeding of the fuel. One of the objects of the present invention is to provide a new and improved fuel injection nozzle which will satisfy these requirements.

Another object is to provide a novel fuel injection nozzle in which the volume of the fuel paths is at a minimum necessary for proper mechanical and hydraulic functioning so as to minimize the effect of the compressibility of the fuel and the elasticity under pressure of the walls of the injection system in contact with the fuel.

A further object is to provide a new and improved spring loaded differential fuel injection nozzle which has a relatively small hydraulic pressure area for opening the valve and a relatively large hydraulic pressure area for holding the valve open, so that more fuel pressure is required to open the valve than to hold it open, and, upon seating, an increased fuel pressure is required to reopen the valve, and which also is small in size and hence adapted for proper installation in limited or difficultly accessible spaces.

Another object is to provide a novel fuel injection nozzle in which any leakage past moving parts is directed into the main fuel stream, thereby obviating the necessity for a leakage drain line from the nozzle, and in which the movable parts can therefore be more freely fitted so as not to stick or become faulty in operation under unfavorable temperature conditions.

An important object of the present invention is to provide a novel fuel injection nozzle in which the rate of fuel emission is not controlled solely by the applied hydraulic pressure, and can, for example, be increased without requiring or being accompanied by an undesirable increase in pressure. Where the rate of fuel emission is a direct function of the applied pressure, the pressure increase at high or maximum engine speeds would frequently result in an undesirable increase in the duration of injection.

The present invention contemplates the provision of a nozzle in which the relation of the applied hydraulic pressure to the quantity of fuel emission may be limited or controlled by selective design.

A more specific object is to provide a new and improved nozzle in which the opening of the valve is controlled at least in part by the rate of fuel flow in such a manner that upon the application of an adequate lifting pressure the valve will open very rapidly a sufficient distance to reduce appreciably the flow resistance across the valve seat and thereby render available immediately a high injection pressure at the discharge tip.

Still another object is to provide a novel fuel injection nozzle in which a flow resistance is utilized to subdivide the fuel pressure, and in which a lifting area substantially larger than the valve area is immediately subjected upon initial valve opening to a pressure differential created by the flow restriction to effect sudden and substantial opening of the valve. By providing a large lifting area, only a small pressure differential is required to hold the valve open, and the remaining pressure is available for injection purposes. The subdivision of the applied pressure permits independent control by selective design of two distinct pressures controlling separate operating functions in the nozzle. Thus, the flow-controlled lifting pressure may be varied at will without affecting the design of the nozzle outlet for proper atomization.

A further object is to provide a novel flow-controlled fuel injection nozzle in which the fuel valve opens and closes with a popping action, i. e., with extreme rapidity when in close proximity to the seat, and in which the difference between the valve opening pressure and the valve closing pressure is controlled to obtain good atomization at idling speeds and also good performance at top or full-load speeds.

Another object is to provide a novel fuel injection nozzle having a plurality of flow restrictions in series and of progressively increasing flow areas for controlling the opening of the valve, including one or more transient or relatively disappearing initial restrictions and a final limiting restriction, whereby a relatively high assisting pressure is available initially when the valve is still near its closed position to cause an immediate increase in valve opening, and a reduced lifting pressure is available thereafter to hold the valve open and to release a larger proportion of the total pressure for injection purposes.

A more specific object is to provide a new and improved flow-controlled fuel injection nozzle having, in addition to the final or limiting flow restriction, an initial transient or disappearing flow restriction effective only when the valve is in close proximity to the seat, and an intermediate transient or disappearing restriction effective over a desired portion, variable by selective design, of the initial part of the valve lift.

Still another object is to provide a nozzle having a novel valve in which the unit closing pressure on the seat area is sufficiently high to collapse the oil film, and in which the valve member is self-aligning with the seat, thereby insuring tight and uniform closing engagement.

Further objects and advantages will become apparent as the description proceeds.

In the accompanying drawings, Figure 1 is a longitudinal sectional view of a pintle type fuel injection nozzle embodying features of the present invention.

Fig. 2 is a fragmentary longitudinal sectional view of one type of fuel injection nozzle to which the features of the present invention are applicable.

Figs. 3 and 4 are transverse sectional views taken respectively along lines 3—3 and 4—4 of Fig. 1.

Fig. 5 is a longitudinal sectional view of a fuel injection nozzle of the nonpintle type embodying features of the present invention.

Fig. 6 is a diagrammatic representation of typical operating characteristics of the two nozzles illustrated in Figs. 1 and 2.

Fig. 7 is a fragmentary sectional view on an enlarged scale of a nozzle with a modified valve construction, and employing a single transient flow resistance.

Fig. 8 is a longitudinal sectional view of a pintle type fuel injection nozzle having a plurality of transient flow resistances in series.

Figs. 9 and 10 are transverse sectional views taken respectively along lines 9—9 and 10—10 of Fig. 8.

Fig. 11 is a longitudinal sectional view of a fuel injection orifice of the nonpintle type having a plurality of transient flow resistances in series.

Fig. 12 is a transverse sectional view taken along the line 12—12 of Fig. 11.

Fig. 13 is a longitudinal sectional view of another modified form of nozzle.

Figs. 14 and 15 are transverse sectional views taken respectively along lines 14—14 and 15—15 of Fig. 13.

While the invention is susceptible of various modifications and alternative constructions, I have shown in the drawings and will herein describe in detail the preferred embodiment, but it is to be understood that I do not thereby intend to limit the invention to the specific form disclosed, but intend to cover all modifications and alternative constructions falling within the spirit and scope of the invention as expressed in the appended claims.

The fuel injection nozzle illustrated in Fig. 1 comprises a suitable body or housing 13. Preferably, the body 13 is in the form of a tubular shell defining an axial bore 14, and having an external peripheral flange 15 at the base end and an internal peripheral flange 16 at the discharge end. The discharge end of the shell 13 is closed by an orifice head 17 which has suitable orifice means with the desired fuel discharge characteristics for proper atomization and penetration, and which preferably is removable to permit substitution for different spray patterns and characteristics. The orifice head 17 may be provided in any desired form, and in the present instance is shown as a circular plate extending snugly through the flange 16 to the outer face thereof, and having an external peripheral flange 18 seating snugly within the bore 14 against the inner face of the flange 16. A tubular spacer 19 having an axial bore 20 is fitted into the shell 13 and serves to hold the plate 17 in position.

A stationary member 21 in the form of a cylindrical plug is fitted into the base end of the shell 13 and serves to hold the spacer 19 in position. Suitable plastic means 22 is pressed into an annular groove 23 having opposed complementary sections in the base end of the shell 13 and the member 21, and serves to seal and maintain the assembly. The member 21 is formed with an axial fuel inlet passage 24 adapted for connection with a fuel pump or other suitable means (not shown) for supplying the fuel to be injected.

It will be understood that the assembly just described constitutes the rigid structure of the nozzle tip, and as such is adapted to be connected to the source of fuel supply, and to be clamped or secured to the engine at the desired point of injection. A nozzle holder or other suitable means, not specifically disclosed herein since per se it forms no part of the present invention, may be utilized for this purpose as is well understood in the art. The rigid structure of the nozzle tip is susceptible of various modifications and alternative forms without departing from the broad aspects of the present invention, and in general provides an internal chamber, defined by the bore 20, adapted for communication with the inlet passage 24 and to discharge through the orifice body 17.

The orifice body 17 may be provided in various forms depending on the injection characteristics desired. Thus, it may be of the single orifice type emitting a jet or spray in any desired direction and of constant or variable dispersion characteristics, or of the multiple orifice type in which the orifices are opened either simultaneously or successively, are orientated to discharge in the same or various different directions, and provide various combinations of jets or sprays of constant or variable dispersion characteristics. The orifice body 17 also may be of the open hole type delivering a noncentrifugal core or a centrifugal envelope or both simultaneously or successively, or may cooperate with a pintle to deliver an annular spray of constant or variable flow characteristics.

The nozzle tip illustrated in Figs. 1, 3 and 4 is of the pintle type. Thus, the orifice body 17 is formed with an axial bore or opening 25 which preferably is of constant cross-sectional area A_b, and which is connected intermediate its ends through a plurality of flow passages 26 to the

fuel chamber 20. In the present instance, the passages 26 open to the bore 25 in radial planes, and hence no centrifugal discharge is obtained.

Extending reciprocably into the bore 25 is a stem or pintle 27 which is generally tapered so as to define upon movement progressively toward open position an annular discharge orifice 28 of gradually increasing area A_o. More specifically, the pintle 27 comprises an inner cylindrical section defining an annular space of constant area always open to the passages 26, and a conical outer end section having a variable area A_p slightly less at the large end than the bore area A_b. In retracted or closed position, the outer end of the pintle 27 is substantially flush with the outer face of the orifice body 17 and defines the minimum annular orifice area A_o. Upon opening of the nozzle, the pintle 27 is projected outwardly progressively into fully open position, and the orifice area A_o is correspondingly increased. By proper correlation of the taper on the pintle 27 and the rate of axial movement, a rate of increase in the orifice area A_o may be obtained giving a graduated rate of injection best suited for efficient combustion.

The pintle 27 is connected for movement with a valve member 29 coacting with a stationary valve seat 30 on the inner face of the plug 21 and defining therewith a valve 31 for controlling the supply of fuel from the passage 24 to the chamber 20. A coil compression spring 32 tends to close the valve 31 with a predetermined spring pressure P_s, and as an incident thereto to retract the pintle 27 into closed position.

Within the broad aspects of the invention, the valve 31 may be of any suitable form or character. In the present instance, the valve seat 30 is located at the inner end of an axial guide bore 33 in the plug 21 open to the chamber 20, and has an annular face defining a pressure inlet passage with a cross sectional area A_v. The movable valve member 29 consists of a ball element which is slidably disposed in the guide bore 33 for movement into and out of concentric engagement with the valve seat 30, and which is supported by a retainer in the form of a flat circular head 34 on the inner end of the pintle 27. Suitable grooves 35 are formed in the peripheral surface of the bore 33 to permit the passage of fuel from the valve 31 to the chamber 20. The spring 32 is seated at one end against the orifice head 17 and at the other end against the retainer 34, and tends to close the nozzle. Preferably, the orifice head 17 is provided with an inwardly extending sleeve 36 for guiding the pintle 17 and retainer 34, and for preventing buckling or displacement of the spring 32.

The fuel pressure on the valve area A_v necessary to open the valve 31, hereinafter referred to as the valve opening pressure (V. O. P.) is determined by the pressure of the spring 32. The spring pressure (P_s) may be varied by substituting either spacers 19 of different lengths or springs 32 of different strength.

If the flow of fuel from the valve 31 to the orifice 28 is unrestricted, a substantial pressure drop across the valve will invariably occur, this drop being equal to the V. O. P. when a pintle is not employed, and only the excess pressure will be available for effecting injection. Such pressure loss occurs in the pintle nozzle illustrated in Fig. 2 which has grooves 35 defining unrestricted flow passages past the ball element 29, and which in all other respects is identical to the nozzle of Fig. 1.

Referring to Fig. 2, upon the application of fuel pressure from any suitable source of timed delivery of metered fuel quantities, static pressure is first applied to that area of the ball element exposed to the valve passage at the valve seat 30, i. e., the valve opening pressure area A_v. When the hydraulic pressure times the area A_v overbalances the spring pressure P_s, the valve 31 will open to permit the flow of fluid to the orifice 28 at which point hydraulic pressure is again built up by reason of the orifice restriction to set up a force equal to the unit hydraulic pressure at the orifice times the cross sectional area of the pintle A_p. Preferably, the maximum area A_p of the pintle 27 is made slightly greater than the valve area A_v. Hence, immediately upon opening the valve 31, a force of larger magnitude is exerted and causes increased deflection of the spring 32, and also a sudden slight increase in opening of the valve 31, thereby reducing the hydraulic restriction at the valve seat 30 and transferring an increased hydraulic pressure to the orifice 28.

The operation will be more clearly understood upon reference to Fig. 6 in which representative performance characteristics are plotted, the scale along the abscissa representing opening of the valve 31, and the scales along the ordinate representing spring pressure in pounds, hydraulic fuel pressure in pounds per square inch, and areas in square inches. Full line A indicates variations in spring pressure for different extents of valve opening. It is desirable that the spring 32 be as small as possible, and hence the pressure varies at a relatively sharp rate. The effective cross sectional area A_p of the pintle 27, at the end face of the nozzle head 17 and determining the size of the orifice 28, is plotted against valve opening along the full line B. Corresponding variations in the area A_o of the orifice 28 are plotted along the full line C. After the valve 31 has opened, and the hydraulic pressure of the incoming fuel has been transferred from the valve seat 30 to the pintle 27, the force of the orifice pressure P_o on the effective area A_p of the pintle 27 must balance the spring pressure P_s to hold the valve open, i. e., $P_s = P_o \times A_p$. Since the pressure at the orifice now equals the pressure at the inlet, no valve restriction remaining present, the total hydraulic pressure necessary to hold the valve 31 open must equal the spring pressure P_s divided by the pintle area A_p, and this pressure increases as the valve opens, as represented by the curve D, due to the progressive increase in spring pressure and the progressive decrease in pintle area. Due to the reservoir effect inherent in the elasticity of the tubing leading to the nozzle, and of other parts of the system (not shown), this increase in pressure is likely to be objectionable since it tends to increase the duration of injection at increasing engine speeds.

One of the important features of the present invention is to provide a nozzle in which the applied hydraulic pressure may be limited and controlled as desired. In general, this objective is accomplished by making the opening of the nozzle as in Fig. 1 at least in part responsive to the rate of fuel flow. More particularly, the valve member 29 is provided with a lifting area A_d larger than the opening valve area A_v and fully exposed to the pressure of the incoming fuel when the valve 31 is opened, and a flow restriction or resistance is interposed between the area A_d and the injection orifice 28 to build up a differential

hydraulic lifting pressure P_d responsive to the rate of flow and separate from the injection pressure at the orifice 28. In Fig. 1, the lifting area A_d is equal to the diametrical area of the ball element, and the grooves 35 are reduced in flow area to define the restriction. The area A_d is made considerably larger than the area A_v so that a relatively small pressure differential is required to move and hold the valve open. The remaining pressure of the total applied pressure is relatively high and is utilized solely for injection purposes at the orifice 28 to obtain the desired atomization and penetration. The subdivision of the pressure to perform the separate functions makes possible a heavy lifting action without objectionably increasing the orifice area A_o or disturbing the injection characteristics.

By a proper selective design of the parts, the total applied pressure may be widely controlled. In Fig. 6, curve E represents a condition in which the necessary applied pressure remains almost constant. Curve F shows the necessary applied pressure increasing slightly at a uniform rate. Curve G, represents the necessary applied pressure as increasing during the initial valve opening partly along the curve D and then actually dropping to below the original value as the valve is moved into fully open position.

The flow restriction may be provided in any suitable manner, and may be varied widely in form and character depending on the operating characteristics desired. Thus, the restriction may be constant or may vary with the valve lift as in Fig. 1. By properly coordinating the changes in orifice area A_o and in the area of the flow restriction A_r occasioned by various heights of valve lift, the applied pressure to obtain any desired height of lift may be controlled at will. Whatever the form of the restriction, the force required to balance the spring 32 will always equal the total pressure P_v times the effective pintle area A_p plus the restriction pressure differential P_d times the remainder of the lifting area A_d. The pressure P_d required is reduced as the area A_d is increased, and hence may be made very small so as to be entirely unobjectionable.

From the foregoing, it will be evident that the flow restriction 35 sets up a primary valve opening assistance, which will hereinafter be referred to as assistance C. Fig. 1 illustrates the assistance C embodied in a nozzle of the pintle type. A nozzle of the nonpintle type embodying an assistance C is illustrated in Fig. 5. This nozzle is closely similar in design to the nozzle of Fig. 1, and hence like parts are identified by the same reference characters, and corresponding parts of modified form are identified by the same reference characters plus the letter *a*. In Fig. 5, the outer end of the bore 25 is provided with a restricted plain hole orifice 28*a*, and otherwise is unobstructed from the passages 26 outwardly. A guide stem 27*a*, supporting the retainer head 34, is slidable in the sleeve 36, but is not of sufficient length to close the passages 26. In this form, the stem 27*a* does not exert a lifting force when the valve 31 is open.

It is important for efficient combustion that the nozzle valve open and close with a popping action, i. e., with extreme rapidity when in close proximity to the seat. As an additional feature of the invention, a second flow restriction may be provided. This restriction has a very small clearance and is located between the valve and the restriction 35 to provide a transient or disappearing initial assistance A.

Fig. 7 illustrates a modified form of nozzle valve with A and C assistances in series. The valve 31*b* comprises a seat 30*b* consisting of a thin annular rib or flange on the inner end of the plug 21*b* and having a flat face circumscribing the closed valve pressure area A_v, and comprises a valve member 29*b*, preferably in the form of a half ball, having a flat diametrical face disposed for engagement concentrically with the valve seat. The spherical surface of the half ball 29*b* is seated for free oscillatory movement in a complemental socket 37. This socket is formed centrally in the retainer head 34*b* which is mounted on the stem or pintle 27*b*, and which is cylindrical in form and concentrically spaced from the spacer 14*b* to define an annular restriction 35*b* remaining constant in effective area A_r throughout the range of valve movement. It will be understood that the flow restriction 35*b* tends to build up a differential pressure acting on the end area A_d of the head 34*b* to establish the assistance C.

The valve seat 30*b* is peripherally relieved by an encircling groove or recess 38 formed in the plug 21*b* to obtain a small seat area. As a result, the seat pressure is sufficiently high to collapse or extrude the oil film between the valve faces when the valve 31*b* is closed.

The bottom of the groove 38 is inclined outwardly toward the face of the valve member 29*b*, and coacts with the peripheral edge of the latter to define a restricted annular flow restriction 39. By inclining the bottom of the groove 38, the seat 30*b* is conveniently provided with a substantial relief, and the effective minimum area or clearance of the small flow resistance 39 may be readily and accurately determined by the use of mathematics, the depth of the seat relief, the angle and the radial dimensions of the half ball 29*b* and seat 30*b* being known. The bottom of the groove 38 being closely spaced from the peripheral edge of the half ball 29*b* also serves approximately to square up the latter with the seat 30*b*. Hence, the ball 29*b* cannot engage the seat 30*b* at an angle sufficiently large to cause damage or result in valve leakage.

The flow restriction 39, when effective, tends to set up a differential hydraulic pressure acting on the diametrical or flat face area of the half ball 29*b* to establish the initial assistance A. Since the surfaces defining the restriction 39 separate axially in the opening movement of the valve 31*b*, the assistance A is transient or disappearing in character, and effective only when the valve member 29*b* is in close proximity to the seat 30*b*.

In operation, when the hydraulic pressure from the source of supply acting on the closed valve area A_v is sufficient to overcome the force of the spring 32*b*, the valve 31*b* will open. After the initial opening movement, the annular restriction 39 builds up a pressure differential which is applied to the entire flat face area A_b of the valve member 29*b*, and which assists the initial force to accelerate rapidly the first portion of the valve movement, so that the valve member 29*b* is caused to leave the seat 30*b* with a popping action. Since the ball area A_b is much larger than the valve area A_v, the differential pressure required to move the valve member 29*b* is considerably lower than the valve opening pressure, and makes available immediately a high pressure for injection with proper atomization. The initial assistance A, however, quickly disappears, thereby releasing more pressure for

injection, and then the final assistance C assumes control in the same manner as in Fig. 1.

The restriction 39 also serves to accelerate rapidly the final closing movement of the valve 31b. As the valve member 29b moves into close proximity to the seat 30b, the restriction 39 again becomes effective, and sets up a differential pressure acting on the ball area A_b in opposition to the closing movement. However, when the rate of flow drops to a point where the assistance A is no longer effective to balance the closing force, the spring 32b will move the valve member 29b rapidly toward the seat 30b to close the valve 31b with a popping action.

The assistance A is therefore effective in determining the valve closing pressure V. C. P., i. e., the residual pressure from the source at which the valve 31b will finally close.

The assistance C is quite sensitive as to proper length and radial clearance. To improve the control over the early portion of the valve lift, an additional transient or disappearing assistance B effective intermediate the assistances A and C may be provided. A nozzle of the pintle type, generally similar to that of Fig. 1 but having a valve of the character shown in Fig. 7 and having assistances A, B and C in series, is shown in Figs. 8 to 10. The parts of this nozzle corresponding to parts of the foregoing forms of nozzles are identified by the same reference numerals plus the letter c.

Referring more particularly to Fig. 8, the retainer head 34c is formed with a peripheral flange 40 which is in sliding engagement with the bore 20c of the spacer sleeve 19c, and which is flattened at spaced points (see Fig. 10) to define flow restrictions 35c establishing the assistance C. It will be noted that the aggregate effective area A_r of the restrictions 35c remains constant throughout the range of valve movement. The assistance A is established as in Fig. 7 by a restricted transient flow restriction 39c defined by the bottom of the groove 38c and the outer edge of the half ball 29c.

The inner end of the valve retainer head 34c is formed with a tapered surface 41 which is adapted to coact with an internal tapered surface 42 in the spacer sleeve 19c to define a transient or disappearing annular flow restriction 43 establishing the assistance B. By selective choice of the angle of the taper, the additional assistance B can be made effective over any desired portion of the early part of the valve lift.

The minimum quantity of fuel that can be injected per valve opening at a sufficiently high injection pressure to insure good atomization is controlled by the difference between the valve opening pressure V. O. P. and the valve closing pressure V. C. P. An increase in the assistance A serves to lower the valve closing pressure V. C. P., and thereby to increase the minimum quantity of injection. At high rates of flow, not involving minimum quantities, the assistance B and/or C may effect a lower valve closing pressure than would be effected by the assistance A at low rates of flow.

The conical form of the restriction 43 affords a convenient manufacturing method for controlling the flow area. More particularly, the surfaces 41 and 42 may be machined to the desired conical form. Then, the spherical socket 37c can be formed to such a depth or the axial dimension of the half ball can be made of such height that, after assembly, engagement of the half ball 29c with the seat 30c will define the desired minimum flow area of the restriction 43.

Figs. 11 and 12 illustrate a fuel injection nozzle of the nonpintle type embodying assistances A, B and C. The construction is closely similar to that in Fig. 8, and hence the corresponding parts thereof are identified by the same reference numerals plus the letter d. In this form, the retainer head 34d does not have a flange 40, but in part is cylindrical and spaced concentrically from the surface of the bore 20d to define the flow resistance 35d establishing the assistance C. The assistances A and B are established in the same manner as in Fig. 8. The orifice head 17d is formed in the inner face with an enlarged axial bore 25d which opens to a small bore defining a restricted plain hole orifice 28d. A square head 44 rigid with the stem 27d is slidable in the bore 25d, and coacts therewith to define a plurality of flow passages 26d from the chamber 20d to the orifice 28d. The head 44 is formed in the free end with an axial bore 45 and a plurality of restricted grooves 46 opening tangentially to the latter from the passages 26d.

In the opening of the nozzle valve 31d, the flat end face of the head 44 moves toward the parallel annular end face of the bore 25d. For the major portion of the valve opening movement, the fuel will pass freely to the orifice 28d and issue therefrom in the form of a noncentrifugal spray core. However, as the valve 31d nears the fully open position, the end faces of the bore 25d and the head 44 move into close proximity and set up a flow restriction, thereby causing the fuel to pass through the grooves 46 to the bore 45. The fuel will now issue from the orifice 28d in the form of a centrifugal envelope.

Figures 13 to 15 illustrate a fuel injection nozzle in which the nozzle valve is located between the outlet and the means defining the flow restriction. A tip body 47 has a base end flange 48 removably clamped against the inside of an end flange 49 on a tubular holder body 50. Mounted in the body 50 are a tubular spacer 51 abutting the tip body 47, an annular plate 52 positioned against the spacer and having a central tapered flow opening 53, and a nut 54 with an axial inlet passage 55 threaded into the base end of the body 50 against the plate to clamp the parts in assembled relation. A clamping plate 56 interfits with the base end of the body 50, and affords means for mounting the nozzle on the engine.

The tip body 47 is formed in opposite ends with axial bores 57 and 58 connected by a valve passage 59. Secured in the outer end of the bore 57 is a plug 60 having an axial passage 61 terminating with a discharge opening 62. A longitudinally fluted valve member 63 is reciprocable in the bore 57 for engagement with a conical seat 64 at the valve passage 59, and is rigid with an axial pintle 65 extending into and coacting with the opening 62 to define an annular discharge orifice. The end of the pintle 65 is tapered inwardly so that upon outward movement it will cause the orifice to increase progressively in effective flow area. The valve member 63 has an axial stem 66 projecting inwardly through the bore 58 and the spacer 51. A coil compression spring 67 interposed between the body 47 and lock nuts 68 adjustably threaded on the stem 66 tends to move the valve member 63 inwardly into engagement with the seat 64 and to retract the pintle 65 into closed position. It will be understood that the fuel under pressure when supplied

through the passage 55 will act on the face portion of the valve member 63 exposed to the valve passage 59 in a direction to open the valve outwardly against the action of the spring 67.

To provide a fuel flow-responsive assistance, an element such as a ball 69, having a diametrical area substantially larger than the valve area defined by the seat 64, is disposed against the inner end of the stem 66 and within the opening 53 for movement with the valve member 63. The inner end of the nut 54 is formed with a bore 70 freely receiving the ball 69, and a light spring 71 therein serves to hold the ball against the stem 66. The ball 69 coasts diametrically with the opening 53 to define an annular flow restriction 72 adapted to increase in effective area upon progressive opening of the valve. Initially, the valve is opened by the pressure of the fuel acting outwardly on the exposed seat area of the valve member 63. As soon as a flow occurs, the restriction 72 acts to build up a differential pressure effective on the diametrical area of the ball 69 to accelerate the valve opening movement.

It is to be understood as to all the nozzles disclosed herein that the forces assisting in the opening of the valve are regulatory in character, viz., they assist in causing the valve to respond to the rate of pressure application of the normal injection occurrence; however, the structure which assists the valve in responding to the fundamental rate of pressure application decreases or renders negative the assisting forces when the valve is subjected to superimposed pressure waves of higher harmonic frequencies. In general, it may be said that if the tendency of the valve is to lift more slowly than desired, assisting forces are generated to aid in the lift, and if the tendency is to lift more rapidly than desired, these forces are automatically decreased and may on occasion actually become negative in character.

I claim as my invention:

1. In a fuel injection nozzle, in combination, a nozzle body having a fuel inlet passage and restricted orifice discharge means, a valve for controlling the supply of fuel from said passage to said discharge means and opening in the direction of fuel flow, spring means tending to seat said valve, said valve having an opening pressure area exposed to the pressure of said fuel and acting in opposition to said spring means, and means defining a constantly open flow restriction in series with said valve in the path of fuel flow to said discharge means and immediately effective in the initial opening movement of said valve to produce a pressure drop and having a lifting pressure area larger than said opening pressure area exposed to the differential pressure set up by said restriction upon the flow of fuel through said valve and acting in opposition to said spring means to provide a valve opening assistance.

2. In a fuel injection nozzle, in combination, a nozzle body having a fuel inlet passage and restricted orifice discharge means, a valve having a seat and a valve member for controlling the supply of fuel from said passage to said discharge means and opening in the direction of fuel flow, spring means tending to seat said valve member, said valve having an opening pressure area exposed to the pressure of said fuel in said passage and acting in opposition to said spring means, a flow restriction separate from the flow area through said seat and the flow area through said orifice discharge means in the path of fuel flow to said discharge means and responsive to the fuel flow in the opening movement of said valve to effect a pressure drop, the flow area of said restriction increasing progressively in the opening movement of said valve, and means defining a lifting pressure area exposed to said pressure drop and acting in opposition to said spring means to provide a valve opening assistance.

3. In a fuel injection nozzle, in combination, a nozzle body having a fuel inlet passage and restricted orifice discharge means, a valve having a seat and a valve member for controlling the supply of fuel from said passage to said discharge means, spring means tending to seat said valve member, said valve having an opening pressure area exposed to the pressure of said fuel and acting in opposition to said spring means, a plurality of flow restrictions of different effective flow areas in series in the path of fuel flow and spaced from said seat, a plurality of pressure areas exposed respectively to the pressure differentials set up by said restrictions and acting in opposition to said spring means, said last mentioned pressure areas being successively effective in the movement of said valve member from closed position to fully open position, and effective in reverse order in the closing movement of said valve member.

4. In a fuel injection nozzle, in combination, a nozzle body having a fuel inlet passage and restricted orifice discharge means, a valve having a seat and a valve member for controlling the supply of fuel from said passage to said discharge means, spring means tending to seat said valve member, said valve having an opening pressure area exposed to the pressure of said fuel and acting in opposition to said spring means, a disappearing flow restriction independent of said seat in the path of the fuel flow to said discharge means and effective during the initial opening movement of said valve member, another flow restriction in the path of the fuel flow effective during a succeeding portion of the valve opening movement, and a plurality of pressure areas exposed respectively to the pressure differentials set up by said restrictions and acting in opposition to said spring means.

5. In a fuel injection nozzle, in combination, a nozzle body having a fuel inlet passage and restricted orifice discharge means, a valve for controlling the supply of fuel from said passage to said discharge means, spring means tending to seat said valve, said valve having an opening pressure area exposed to the pressure of said fuel and acting in opposition to said spring means, a rapidly disappearing flow restriction in the path of the fuel flow effective only during the initial opening and final closing movements of said valve, a gradually disappearing flow restriction in the path of the fuel flow effective during the intermediate range of valve movements, a third flow restriction in the path of the fuel flow effective when said first mentioned restrictions are ineffective, and a plurality of pressure areas exposed respectively to the pressure differentials set up by said restrictions and acting in opposition to said spring means.

6. In a fuel injection nozzle, in combination, a nozzle body having a fuel inlet passage and restricted orifice discharge means, a valve having a seat and a valve member for controlling the supply of fuel from said passage to said discharge means, spring means tending to seat said valve member, said valve having a relatively

small opening pressure area exposed to the pressure of said fuel and acting in opposition to said spring means, an open flow restriction spaced outwardly from said seat in the path of said fuel effective during an initial portion of the valve movement and disappearing as said valve member moves toward open position, and a relatively large pressure area acted on by the differential pressure set up by said restriction and acting in opposition to said spring means.

7. In a fuel injection nozzle, in combination, a casing having a central chamber, an orifice head in one end of said casing and having orifice discharge means opening from said chamber, a tubular spacer in said casing against said head, a fitting in said casing against said spacer and having a fuel inlet passage opening to said chamber, an annular valve seat on said fitting about the discharge end of said passage, a valve member having a stem slidable in said orifice head and coacting axially with said seat, spring means tending to urge said valve member toward said seat, said valve member when seated having a relatively small opening pressure area defined by said seat and exposed to the fuel pressure in said passage acting in opposition to said spring means, and having a relatively large lifting pressure area adapted to be exposed to said fuel pressure when said valve member is away from said seat, means defining an open flow restriction in the path of the fuel between said lifting area and said orifice discharge means, and a pintle on said stem and coacting with said discharge means to provide a graduated orifice opening.

8. In a fuel injection nozzle, in combination, a casing having a central chamber and orifice discharge means opening from said chamber, a body having a fuel inlet passage opening to said chamber, an annular valve seat on said body about the discharge end of said passage, a valve member coacting axially with said seat, spring means tending to urge said valve member toward said seat, said valve member when seated having a relatively small opening pressure area defined by said seat and exposed to the fuel pressure in said passage acting in opposition to said spring means, and having a relatively large lifting pressure area adapted to be exposed to said fuel pressure when said valve member is away from said seat, and means defining a variable flow restriction about said valve member in the path of the fuel between said lifting area and said orifice discharge means.

9. In a fuel injection nozzle, in combination, a casing having a central chamber, an orifice head in one end of said casing and having a discharge bore opening from said chamber, a spacer in said casing against said head, a body in said casing against said spacer and having a fuel inlet passage opening to said chamber, a guide bore in said body, an annular valve seat on said body at the inner end of said guide bore about the discharge end of said passage, a valve head having a stem slidable in said discharge bore, a ball element on said valve head and slidable in said guide bore to coact axially with said seat, spring means acting on said valve head to urge said ball element toward said seat, and means defining a flow restriction about said ball element to effect a pressure drop between said seat and said discharge bore.

10. In a fuel injection nozzle, in combination, a casing having a central chamber, an orifice head in one end of said casing and having a discharge bore opening from said chamber, a spacer in said casing against said head, a body in said casing against said spacer and having a fuel inlet passage opening to said chamber, a guide bore in said body, an annular valve seat on said body at the inner end of said guide bore about the discharge end of said passage, a valve head having a stem slidable in said discharge bore, a ball element on said valve head and slidable in said guide bore to coact axially with said seat, spring means acting on said valve head to urge said ball element toward said seat, means defining a flow restriction about said ball element to effect a pressure drop between said seat and said discharge bore, and a pintle on said stem and coacting with said discharge bore to define an annular discharge orifice.

11. In a fuel injection nozzle, in combination, a hollow body having a discharge outlet and an inlet passage, an annular flat-face valve seat at the discharge end of said passage, a valve head movable axially of said seat and having a partial spherical socket in one end, a partial ball adjustably mounted in said socket and having a flat face adapted for concentric engagement with said seat, means coacting with said ball to define a flow restriction in the path of the fuel flow from said seat and adapted to set up a differential pressure acting on said ball in the opening direction of said ball, and spring means coacting with said head to urge said ball toward and against said seat.

12. In a fuel injection nozzle, in combination, a body having a cylindrical chamber with a discharge outlet at one end and an axial inlet passage at the other end, an annular flange in said body defining a flat-face valve seat about the discharge end of said inlet passage, an annular clearance groove encircling said flange and having a bottom surface inclined outwardly toward the plane of the valve face, a cylindrical valve head movable axially in said chamber and spaced concentrically thereto with an annular clearance defining a restricted flow resistance, a partial spherical socket formed in the end of said head opposite said valve seat, a partial ball freely disposed in said socket for angular adjustment and having a flat face adapted for concentric engagement with said seat and adapted at the peripheral edge to coact with said bottom surface of said groove to define a restricted flow resistance adapted to disappear as said ball moves from said seat, and spring means tending to urge said ball into engagement with said seat.

13. In a fuel injection nozzle, in combination, a body having a central chamber with a discharge outlet at one end and an outlet passage at the other end, a flange in said body defining an annular valve seat at the discharge end of said inlet passage, an annular clearance groove encircling said flange and having a bottom surface inclined outwardly toward the plane of said seat, a valve head movable axially of said seat in said chamber and coacting therewith to define a restricted flow resistance, a socket formed in the end of said head opposite said valve seat, a partial ball freely disposed in said socket for angular adjustment and having a flat face adapted for concentric engagement with said seat and adapted at the peripheral edge to coact with said groove to define a restricted flow resistance, and spring means tending to urge said partial ball into engagement with said seat.

14. In a fuel injection nozzle, in combination, a hollow body having a discharge outlet and an

inlet passage, an annular valve seat at the discharge end of said passage, an annular clearance groove encircling said seat and being inclined outwardly toward the plane of said seat, a valve head movable axially of said seat and having a socket in one end, a ball element adjustably mounted in said socket and having a valve face adapted for engagement with said seat and coacting with said groove to define an annular flow restriction when said element is in close proximity to said seat, and spring means coacting with said head to urge said ball element into engagement with said seat.

15. In a fuel injection nozzle, in combination, a hollow body having a central chamber with a discharge outlet at one end and an inlet passage at the other end, an annular flange defining a flat-face valve seat at the discharge end of said passage, a clearance groove encircling said flange and having a bottom inclined outwardly toward the plane of the valve face, a valve head having a peripheral flange slidable in said chamber and notched to define a restricted flow resistance, the free end of said head being conical in form and coacting with a conical surface in said body to define a second annular flow resistance, a hemispherical recess in the free end of said head opposite said seat, a partial ball having a spherical portion mounted for self adjustment in said socket and having a flat area disposed for engagement with said valve seat and coacting at its peripheral edge with the bottom of said groove to define a third restricted annular flow resistance, spring means acting on said head in a direction to move said ball toward said valve seat and said head toward said conical surface, and a pintle movable with said head and coacting with said discharge outlet to define a restricted annular discharge orifice of progressively increasing flow area as said ball moves away from said seat.

16. In a fuel injection nozzle, in combination, a hollow body having a central chamber with a restricted discharge orifice at one end and an inlet passage at the other end, an annular flange defining a flat-face valve seat at the discharge end of said passage, a clearance groove encircling said flange and having a bottom inclined outwardly toward the plane of the valve face, a valve head having a peripheral flange slidable in said chamber and notched to define a restricted flow resistance, the free end of said head being conical in form and coacting with a conical surface in said body to define a transient annular flow resistance, a recess in the free end of said head opposite said seat, a ball element having a spherical portion mounted for self adjustment in said recess and having a flat area disposed for engagement with said seat and coacting at its peripheral edge with the bottom of said groove to define a transient annular flow resistance effective when said ball element is in close proximity to said seat, and spring means acting on said head in a direction to move said ball element toward said seat and said head toward said conical surface.

17. In a fuel injection nozzle, in combination, a hollow body having a central chamber with a plain hole discharge orifice at one end and an inlet passage at the other end, means defining an annular valve seat at the discharge end of said passage, a clearance groove encircling said seat and having a bottom inclined outwardly toward the plane of the seat face, a valve head slidable in said chamber and coacting therewith to define a restricted flow resistance. the free end of said head being inclined in form and coacting with a complemental portion of said body to define a second flow resistance over a portion of its movement, a valve element mounted for self adjustment on said head and having a flat area disposed for engagement with said seat and coacting with the bottom of said groove to define a third flow resistance when said valve element is in close proximity to said seat, spring means acting on said head in a direction to move said valve element toward said seat, and means movable with said head and coacting with the inlet of said discharge orifice to cause the emission of the fuel first in the form of a non-centrifugal core and then in the form of a centrifugal envelope as said valve element moves into fully open position.

18. In a fuel injection nozzle, in combination, a casing having an outlet passage, spring seated valve means for controlling the supply of fuel under pressure to said passage, a pintle connected to said valve means for movement therewith and extending reciprocally into said passage to define an annular outlet orifice, the outer end of said pintle being formed with an axially inwardly tapered undercut to provide a graduated orifice opening, and means defining a restriction in the path of fuel flow and responsive to the fuel flow over a range of valve movement between full open and full closed positions to set up a pressure acting in a direction to open said valve means and to move said pintle outwardly.

19. In a fuel injection nozzle, in combination, a hollow body having a central chamber with a discharge orifice at one end and an inlet passage at the other end, means defining an annular valve seat at the discharge end of said passage, a clearance groove encircling said seat and having a bottom inclined outwardly toward the plane of the seat face, a valve head slidable in said chamber and coacting therewith to define a restricted flow resistance, the free end of said head being inclined in form and coacting with a complemental portion of said body to define a second flow resistance over a portion of its movement, a valve element mounted for self adjustment on said head and having a flat area disposed for engagement with said seat and coacting with the bottom of said groove to define a third flow resistance when said valve element is in close proximity to said seat and spring means acting on said head in a direction to move said valve element toward said seat.

20. In a fuel injection nozzle, in combination, a nozzle body having a fuel flow passage and restricted orifice discharge means opening therefrom, a valve in said passage having a seat and a valve member for controlling the supply of fuel through said passage to said discharge means, spring means tending to seat said valve member, said valve member having a relatively small opening pressure area exposed to the pressure of said fuel and acting in opposition to said spring means, and means movable with said valve member and coacting peripherally with said passage to define an open flow restriction spaced from said seat in the path of fuel flow and effective during a portion of the valve movement to set up a differential pressure upon the flow of fuel therethrough, said passage being formed in the region of said restriction with a longitudinal groove increasing progressively in flow area toward said discharge means so as to cause said flow restriction to decrease progressively in accordance with the opening movement of said valve member, said

last mentioned means defining a relatively large pressure area adapted to be acted on by said differential pressure to control the rate of movement of said valve member.

21. In a fuel injection nozzle, in combination, a nozzle body having a fuel flow passage and restricted orifice discharge means opening therefrom, a valve in said passage having a seat and a valve member for controlling the supply of fuel through said passage to said discharge means, spring means tending to seat said valve member, said valve member having a relatively small opening pressure area exposed to the pressure of said fuel and acting in opposition to said spring means, means movable with said valve member and coacting with said passage to define an open flow restriction increasing progressively in flow area upon movement of said valve member through a predetermined range toward open position and defining a relatively large pressure area adapted to be acted upon by the differential pressure set up by said restriction in response to fuel flow and acting to control the rate of movement of said valve member, and additional means movable with said valve member defining another flow restriction in the path of fuel flow through said passage of greater flow area than the initial flow area of said first mentioned restriction and having a relatively large pressure area adapted to be acted on by the differential pressure set up by said other restriction in response to fuel flow to control the movement of said valve member.

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