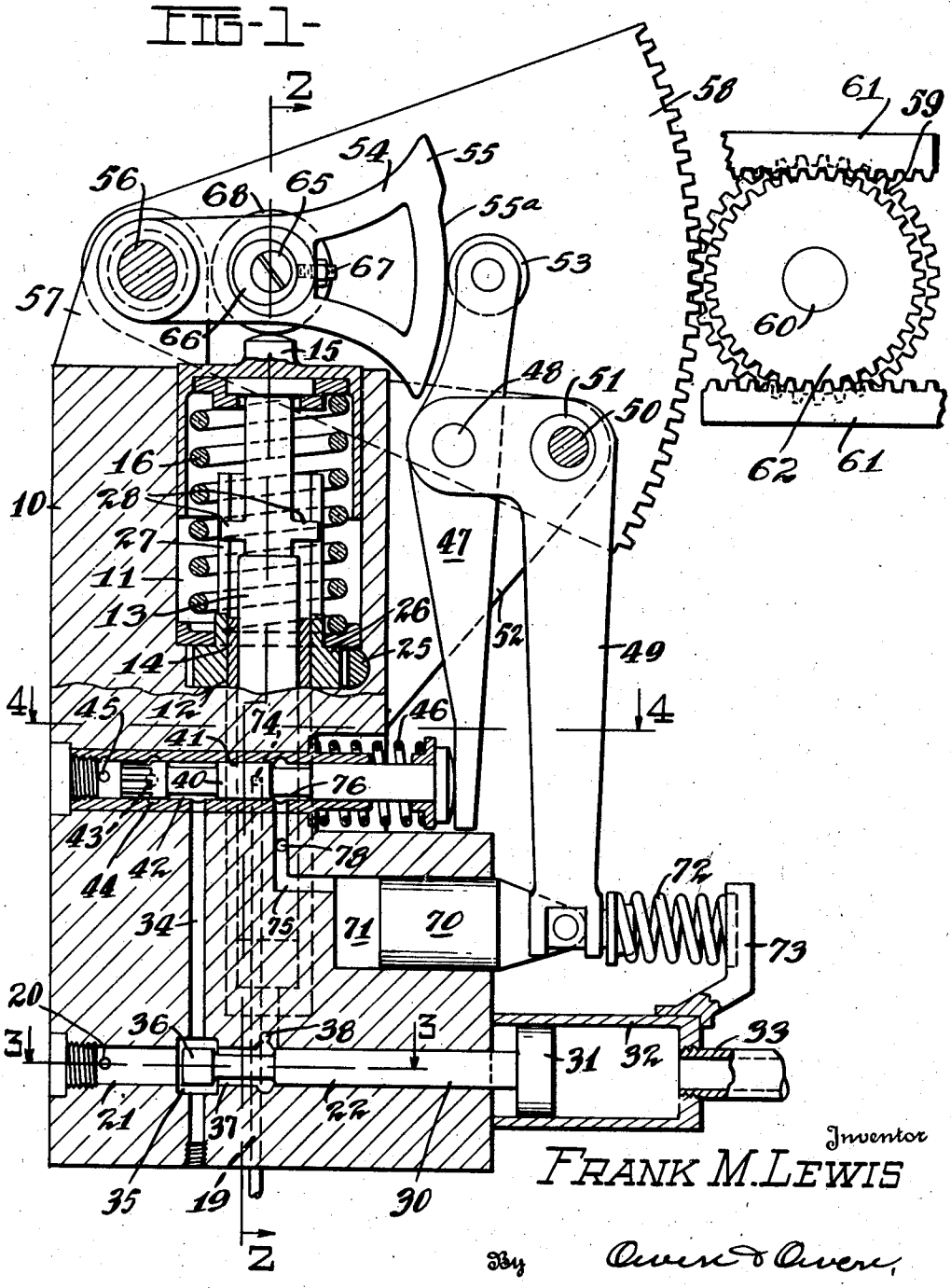
Oct. 12, 1948. F. M. LEWIS 2,450,898

FUEL INJECTOR CONTROL MECHANISM FOR FREE PISTON ENGINES

Filed Oct. 5, 1944 5 Sheets-Sheet 1

FIG-1-



Inventor

FRANK M. LEWIS

By Owen & Owen

Attorneys

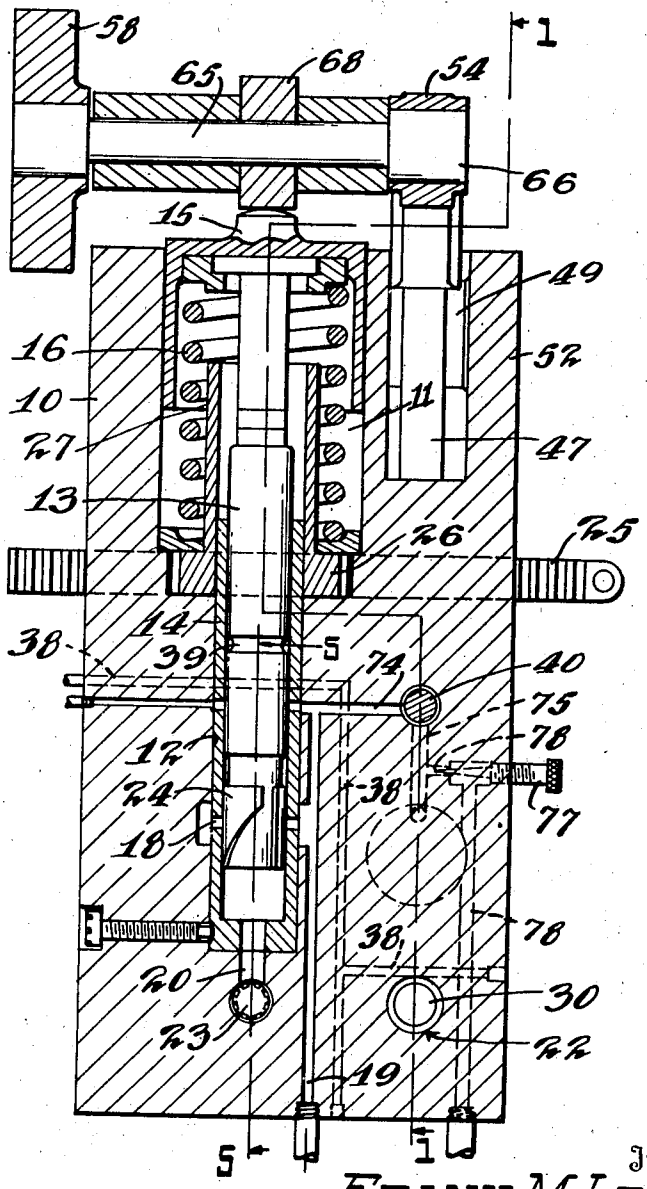
Oct. 12, 1948. F. M. LEWIS 2,450,898

FUEL INJECTOR CONTROL MECHANISM FOR FREE PISTON ENGINES

Filed Oct. 5, 1944

5 Sheets-Sheet 2

FIG-2-



Inventor

FRANK M. LEWIS

By Owen & Owen,

Attorneys

Oct. 12, 1948. F. M. LEWIS 2,450,898

FUEL INJECTOR CONTROL MECHANISM FOR FREE PISTON ENGINES

Filed Oct. 5, 1944

5 Sheets-Sheet 3

FIG-3-

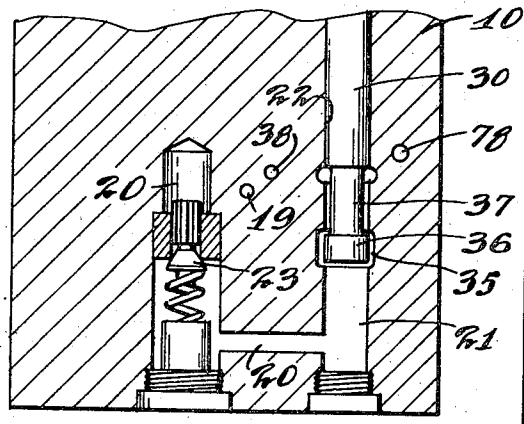


FIG-5-

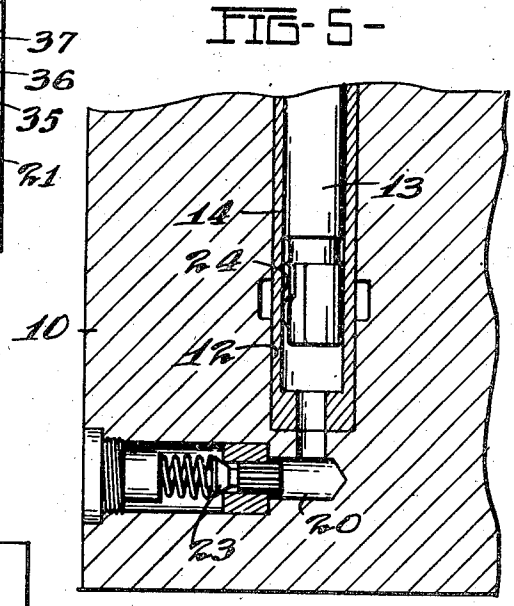
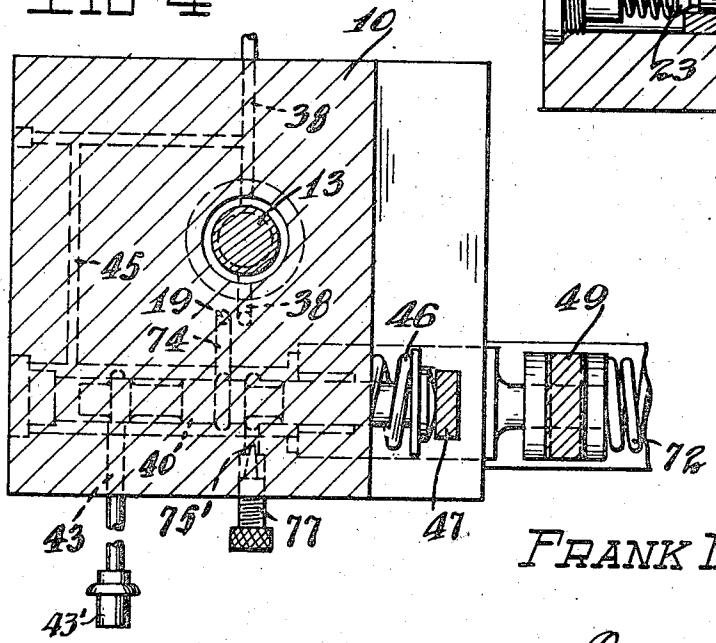


FIG-4-



Inventor

FRANK M. LEWIS

By Owen & Owen,

Attorneys

Oct. 12, 1948. F. M. LEWIS 2,450,898

FUEL INJECTOR CONTROL MECHANISM FOR FREE PISTON ENGINES

Filed Oct. 5, 1944

5 Sheets-Sheet 4

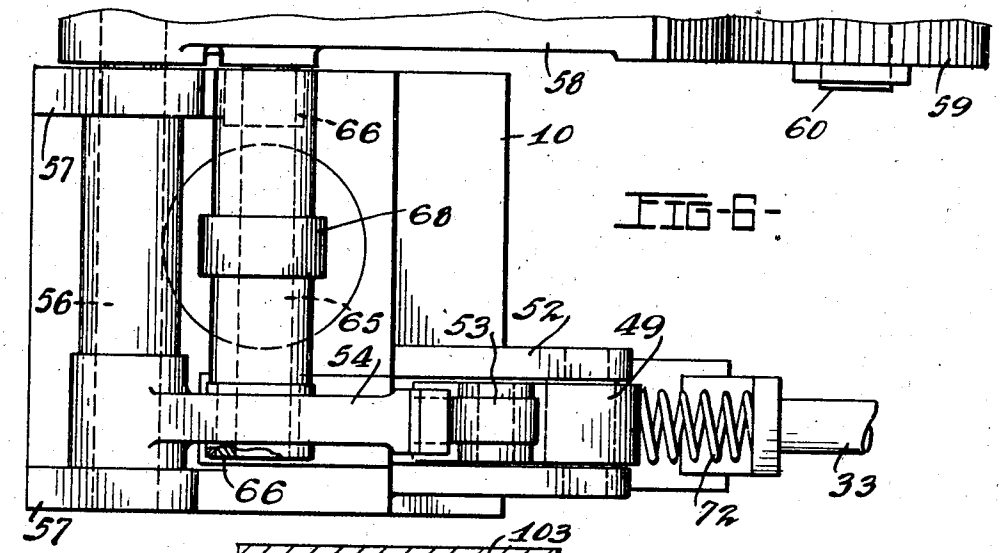


FIG-6-

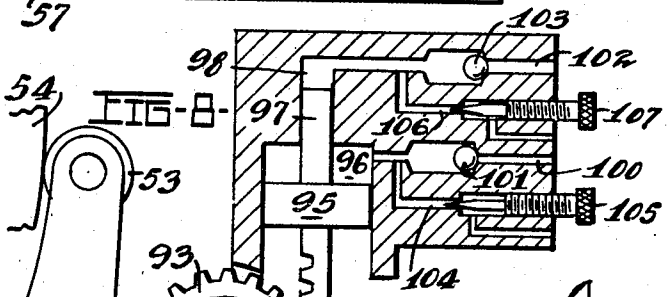


FIG-8-

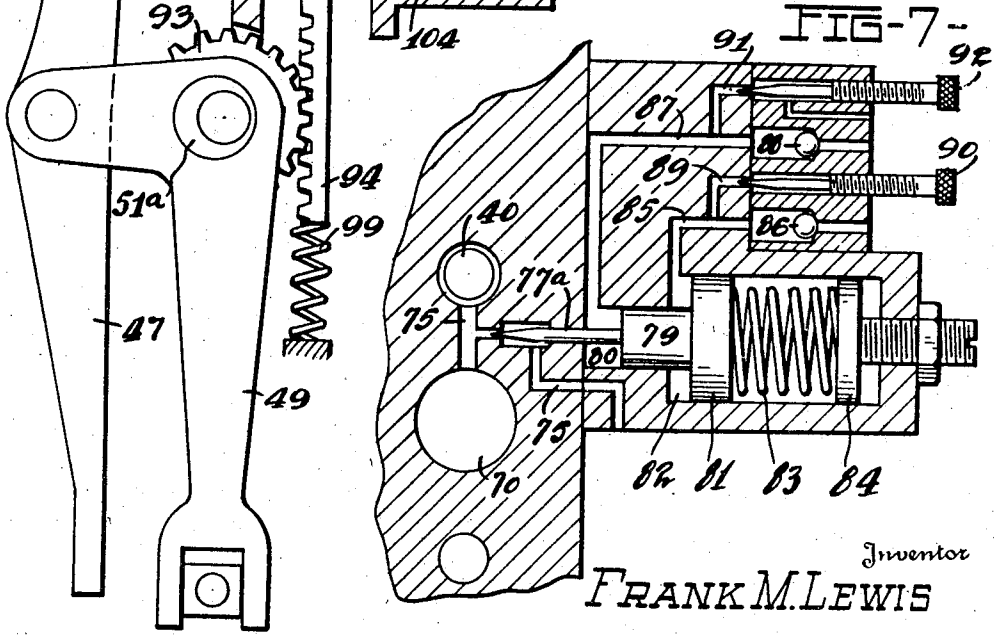


FIG-7-

Inventor

FRANK M. LEWIS

By Avery & Avery

Attorneys

Oct. 12, 1948. F. M. LEWIS 2,450,898

FUEL INJECTOR CONTROL MECHANISM FOR FREE PISTON ENGINES

Filed Oct. 5, 1944 5 Sheets-Sheet 5

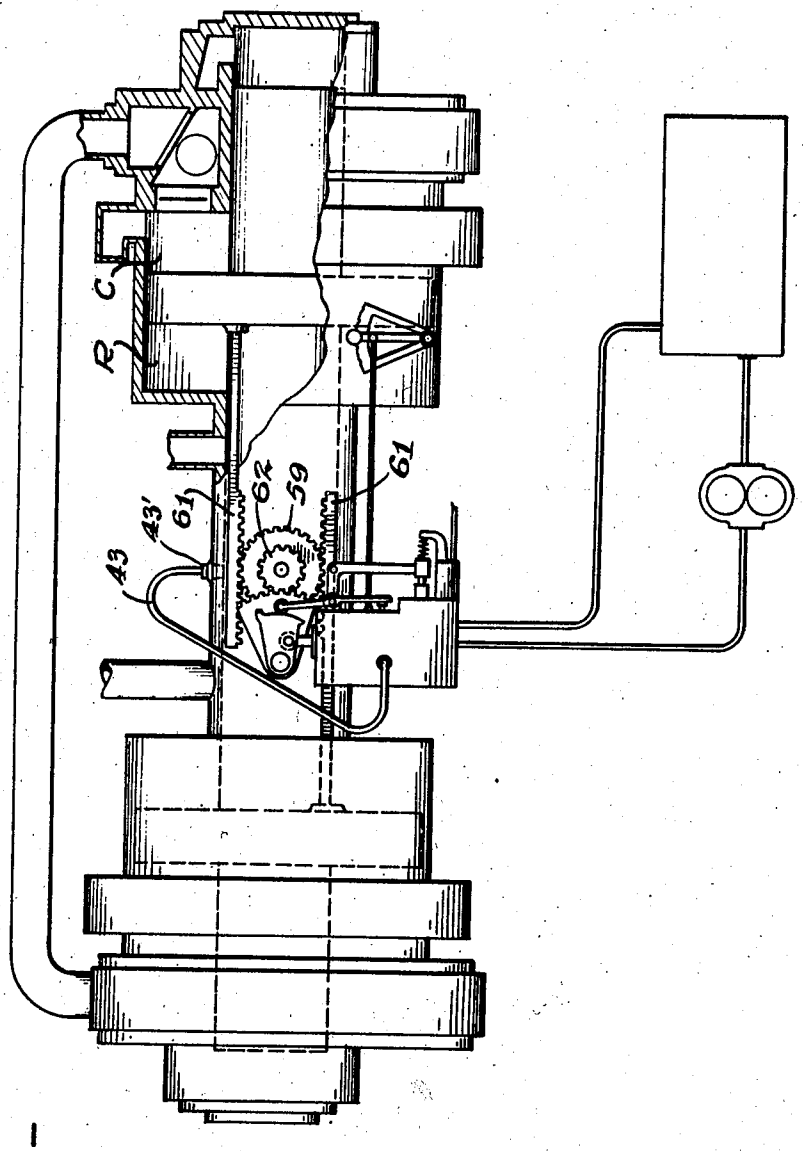


FIG-5-

INVENTOR.
FRANK M. LEWIS
BY
Owen & Owen
ATTYS.

Patented Oct. 12, 1948

2,450,898

UNITED STATES PATENT OFFICE

2,450,898

FUEL INJECTOR CONTROL MECHANISM FOR FREE PISTON ENGINES

Frank M. Lewis, Weston, Mass., assignor, by mesne assignments, to Lima-Hamilton Corporation, Hamilton, Ohio, a corporation of Virginia

Application October 5, 1944, Serial No. 557,284

22 Claims. (Cl. 123—46)

1

This invention relates to fuel injection means for use in connection with internal combustion engines of the free piston type.

In the running of engines of this character, the position attained by the pistons at the combustion end of their strokes, when a fuel charge is to be injected, will vary with the load and the speed. Therefore, if the usual type of fuel injection is used wherein the injections occur when the pistons reach a certain point in the cylinder, this variation in stroke induces undesirable variation in the timing of injections of the fuel with reference to the combustion end of the stroke, so that the injection may occur too early, too late or possibly not at all.

The object of the invention is to obviate the above-noted objections by the provision of a novel and efficient means which is operable by running of the free piston engine to time the fuel injections with respect to the relation of the pistons to the ends of their compression strokes, regardless of how the length of the strokes may vary with variations of the load and speed of the engine.

Another object of the invention is the provision of a novel and efficient fuel pump of the character described, which, in its operation, will utilize a large part of the engine piston stroke to pump fuel, thus obviating the mechanical difficulties arising ordinarily in the operation of such a pump due to the fuel injection taking place at a very small portion of the piston motion at the end of a compression stroke.

Further objects and advantages of the invention will be apparent from the following description, and from the accompanying drawings, in which—

Figure 1 is a vertical section of an apparatus embodying the invention, with parts in full and with the lower portion offset from the center line of the pump plunger, as shown by the dotted line 1—1 in Fig. 2; Fig. 2 is a vertical section on the line 2—2 in Fig. 1; Fig. 3 is a fragmentary cross-section on the line 3—3 in Fig. 1; Fig. 4 is a cross-section on the line 4—4 in Fig. 1; Fig. 5 is a fragmentary section on the line 5—5 in Fig. 2; Fig. 6 is a top plan view of the apparatus, with parts broken away; Fig. 7 is a vertical fragmentary section of a modified bleed feature for the injection timing piston; Fig. 8 is a fragmentary section illustrating a modified feature of the timing means; and Fig. 9 is a diagrammatic side elevation of an engine having an injection means in accordance with the present invention.

Referring to the drawings, 10 designates the

2

stationary body of a fuel injection means embodying the present invention and which is carried by a bracket, or in any other suitable manner, at the side of an associated internal combustion engine of the free piston type in convenient position to be actuated by the piston synchronizing means of the engine through an intermediate mechanism hereinafter described. The general organization of the parts as applied to a free piston engine is shown in Fig. 9. The pump body 10, which in the illustrated embodiment of the invention is rectangular in cross-section, is provided longitudinally in its top end portion with a large bore 11 and from the bottom end of this with a smaller bore 12 which terminates short of the lower end of the body, as best shown in Fig. 2. A pump plunger 13 is mounted for longitudinal reciprocatory movements in the bore 12, preferably having a bearing in a lining 14 therein, and has its outer end projecting into the bore 11 and connected to a cup 15 reciprocably movable therein. An inward stroke is imparted to the plunger 13 during the compression stroke of the engine pistons by means hereinafter described, and such inward movement is resisted by a coiled spring 16 disposed in the bore 11 between its bottom and the cup 15 in surrounding relation to the plunger.

The lower end of the lining 14 or of the bore receiving the pump plunger 13 has inlet ports 18 in its side wall in communication with an oil supply passage 19 in the body 10, such ports being located a short distance above the lower end of the bore. This end of the bore is provided with an outlet passage 20 leading to a charge chamber 21 in the inner end of a bore 22 (Fig. 1) that is provided transversely in the lower end portion of the body 10. A check valve (Figs. 3 and 5) is mounted in the passage 20 and opens outwardly relative to the lower end of the pump bore.

The pump plunger 13 cooperates with the fuel admission port 18 to regulate its closing in a well-known manually or automatically variable manner upon an inward compression stroke of the plunger and to open it at the end of such stroke. For this purpose, the inner end of the plunger is provided with axially spaced relief portions which successively register with the port 18 during movements of the plunger and are partially divided by a helical edged portion 24 which, in an inward movement of the plunger, moves across the port 18 and effects a closing thereof. The period of compressing action of the plunger 13 takes place during the middle portion of its instroke and is regulated by a turning of the

plunger, which may be accomplished manually or in a governor-controlled manner, by the movement of a rack-bar 25 in engagement with a pinion 26 in connection with the plunger, thus regulating the amount of fuel pumped into the charge chamber 21 at each pumping stroke of the plunger 13. In the present instance, the pinion 26 has a hub sleeve 27 projecting upward therefrom within the bore 11 and longitudinally slotted at opposite sides to slidingly receive the projections 28 on opposite sides of the plunger, as best shown in Fig. 1. It is thus apparent that rotary adjustment of the plunger to regulate the amounts of the charge to be pumped thereby is effected by a rotation of the pinion sleeve 27 and that its engagement with the sleeve will not prevent longitudinal movements of the plunger.

A charge ejecting plunger 30 (Fig. 1) is mounted in the bore 22 and is yieldingly movable in an outward direction to oppose the pumping of a charge into the chamber 21 by the pump plunger. While the yielding means opposing the outward movement of the plunger 30 may be of any suitable character, it is shown, in the present instance, as being pneumatic and as comprising a piston 31 on the outer end of the plunger working in a cylinder 32 that is supplied with a high fluid pressure through a supply line 33. It is found that a pressure of approximately 1000 pounds per square inch is suitable for the purpose. An outlet passage 34 is provided from the charge chamber 21 and this communicates with such chamber through an annular recess 35 in the chamber wall. The passage 34 is normally closed by a trigger plunger, as hereinafter described, and is not opened to the fuel injection nozzle with which it communicates until the pump plunger 13 is very close to the end of its instroke.

The plunger 30 is provided at its inner end with a land 36 that is slightly less in depth than the width of the recess 35, so that when the plunger is at the inner end of its movement, the charge chamber 21 is closed to the recess and the recess is opened at its opposite edge through a recessed portion 37 in the plunger to a relief passage 38 in the body 10. As the plunger 30 begins to move outward under the compressing action of a charge in the chamber 21, the communication between the recesses 35 and 37 will be closed at approximately the time when the inner end of the land 36 uncovers the communication between the chamber and the recess 35. The plunger 30 moves outward a considerable extent under the force of the fuel charge being pumped into the chamber 21, so that when the outlet passage 34 is opened to the injection nozzle, the charge is forcefully ejected through the passage by the inward movement of the plunger 30 under its inward actuating force. Due to the difference in areas of the piston 31 and the inner end of the plunger 30, the ejecting pressure applied to the charge by the plunger is considerably greater than the pressure acting on the piston. The inward movement of the plunger 30 is stopped immediately after the inner edge of the land 36 has passed the inner edge of the recess 35 due to the hydraulic lock existing in the charge chamber 21 by reason of the only release of oil therefrom being through said recess and the passage 34, which are now closed. The relief passage 38 is interrupted by the pump plunger 13 and is opened when the plunger is at the lower end of its stroke due to a surrounding recess 39 in the plunger moving into register with the relief passage, as best shown in Fig. 2. The purpose of this relief is to prevent dribbling at the nozzle when the plunger 30 has moved inwardly sufficiently to close communication between charge chamber 21 and passage 34.

The trigger valve 40 (Fig. 1, Fig. 2) which controls the timed release of a charge to the injection nozzle, is of plunger form and mounted in a bore 41 disposed crosswise of the body 10 above the ejection plunger 30 and into which bore the charge ejecting passage 34 opens. The valve 40 has an elongated recess 42 which, when the valve is at substantially the inner end of its movement, opens communication between the passage 34 and an outlet passage 43 leading to the fuel injection nozzle (not shown) of the engine. An annular recess 44 is provided in the wall of the bore 41 at the inner end of the passage 43, and this recess is normally closed by a land portion of the valve. A relief passage 45 opens communication between the inner closed end of the bore 41 and the outlet end portion of the passage 38 (Fig. 4), which is disposed at the outer side of the pump plunger 13. When the valve 40 is in its outward or closed position, the passages 43 and 45 are in communication, thus relieving pressure in the nozzle line 43 and preventing dribbling.

A coiled compression spring 46 acts on the outer end of the trigger valve 40 to normally hold it in outward position, or in closed relation to the fuel ejection passage 43, and a quick inward movement is imparted to the valve by the sudden movement of a trip-lever 47 to open the ejection passage 34, 43 for the properly timed emission of a charge. This trip lever is actuated in proper synchronized relation to the piston movement by the actuating means hereinafter described, and has its fulcrum pin 48 mounted in the short inwardly projecting arm of a bell crank lever 49, which lever is in turn carried by a fulcrum pin 50 through the medium of an eccentric bushing 51. The fulcrum pin 50 is mounted in a forked bracket arm 52 projecting from the upper end portion of the body 10, and the trip lever 47 projects upward through the fork opening of this bracket, as shown in Figs. 1 and 6. The lever 47 is disposed lengthwise of the body 10 or vertically, in the present instance, and has its lower long arm in engagement with the outer end of the trigger valve 40 and its upper arm projecting above the bracket 52 and carrying a roller 53 which rides against the peripheral face of a segmental rocker arm 54. Such peripheral face, except at its upper end portion, is concentric to the rocking axis of the arm and at such upper end portion is provided with a raised or outwardly projecting cam portion 55. It is apparent that an outward pressure of the trigger valve 40 against the lower end of the trip lever 47 holds its roller 53 in rolling contact with the peripheral face of the rocker arm 54 and with the cam portion 55 of such face as it traverses such face and cam, and that as the cam moves into engagement with the roller, a sudden tripping movement will be imparted to the lever 47 to effect an inward movement of the trigger valve to release a fuel charge.

The rocker arm 54 is carried by a rocker shaft 56 (Figs. 1 and 6) that is mounted in spaced bracket arms 57 at the upper end of the body 10. A segmental rocker arm 58 fixedly projects from one end of the shaft 56 in the direction of projection of the rocker-arm 54 and has its peripheral edge forming a segmental gear in engagement with a driving pinion 59 mounted on the pinion shaft 60 of the piston synchronizing means of the engine, Fig. 9. In the present instance,

each air compressor piston of the engine has a rack-bar 61 projecting inwardly therefrom in laterally spaced lapping relation and a synchronizing pinion 62 is mounted therebetween on the shaft 60 in engagement at opposite sides of the shaft axis with the racks, as well understood in the art. It is apparent that this rack and pinion connection between the engine pistons causes them to have uniform inward and outward stroke movements and that the connection of the shaft 60 with the rocker shaft 56 through the segmental rocker arm 58 and pinion 59 causes the rotary reciprocatory movements of the shaft 60 to impart corresponding movements to the shaft 56, with the inward and outward rocking movements of the rocker members 54 and 58 relative to the associated pump plunger 13 taking place, respectively, during the compression and outward power strokes of the engine pistons.

The rocker shaft 56 is disposed at one side of the axis of the pump plunger 13 transverse thereto and the rocker arms 54 and 58 have a common radial center plane which crosses over the outer end of the plunger 13. A shaft 65 connects the arms 54 and 58 in said plane, being disposed directly over the axis of the plunger 13 and has eccentric journals 66 mounted for rotary adjusting movements in the arms. A set-screw 67 is carried by the arm 54 and coacts with its eccentric 66 to hold the shaft in adjusted position. A roller 68 is mounted on the shaft 65 intermediate the arms 54 and 58 in position to bear centrally on the top of the plunger head 15 and impart an inward stroke to the plunger against the tension of the spring 16 during an inward or clockwise rocking movement of the rocker arms. It is apparent that during the major portion of this inward stroke rocking movement of the arm 54, its plain peripheral surface 55a will be in coaction with the roller 53 of the trip lever 47, so that no movement is imparted to such lever, and that when the rocker arm is close to the limit of its inward stroke, the cam projection 55 of the arm will coact with the roller 53 of the trip lever 47 and impart a sudden inward movement of the trigger valve 40 to open fuel charge injection position. The engagement of the cam portion 55 with the trip lever roller is timed to take place in predetermined relation to the end of piston compression strokes and during the speed changing movement of the engine pistons at the end of such strokes preparatory to a reversal of the piston movements. This timing may be accurately effected by an adjustment of the eccentric portions 66 of the shaft carrying the roll 68 and eccentric 51 of lever 49, so that the tripping action will take place at the most desirable point in an engine cycle under one condition of use.

Should the length of the working strokes of the engine pistons be increased over normal, either automatically or by means of an engine stroke control device, the fuel injection timing is automatically adjusted with respect to the compression stroke terminal positions of the pistons by means of a mechanism which will now be described and which includes the rocker lever 49 carrying the trip lever 47. The long arm of the lever 49 is in connection with the outer stem portion of a timing piston 70, so that a reciprocatory movement of piston 70 imparts a rocking movement to arm 49. Oil pressure in the inner end of the chamber 71 tends to move plunger 70 outward and a coiled compression spring 72 interposed between the outer end of the plunger stem and bracket 73 on the body 10 tends to move plunger 70 inward. Oil from the constant pressure supply passage 19 in the body 10 is supplied to the cylinder 71 through passages 74 and 75 (Figs. 1 and 2), which passages communicate with the bore 41 for the trigger valve 40 and are placed in open connection through an axially elongated recess 76 in the trigger valve when such valve is at the limit of its inward stroke. A needle valve 77 is mounted in the body 10 in position to regulate the opening of a bleed passage 78 from the passage 75 and which leads to any suitable point of drainage which may be the source from which the oil is taken by a constant pressure pump supplying passage 19. This valve is so adjusted that at normal stroke an equal quantity of oil is lost from cylinder 71 to that added with each stroke of the trigger plunger 40.

In the operation of the pump or fuel injecting means illustrated, the pump plunger 13 will be depressed to pump an oil charge into the chamber 21 during the compression stroke of the engine pistons, such charge compression taking place during the intermediate portion of the plunger movement. As the charge is forced into the chamber 21, the injection plunger 30 is moved outward against its resisting force to full open position of the discharge passage 34, the extent of movement of the plunger depending on the volume of charge pumped into the chamber 21. The check valve 23 in the passage to chamber 21 closes against any back movement of the charge from the chamber. When the pump plunger 13 is near the end of its instroke and the pistons are about to or beginning to slow down for reversal of movement, the cam 55 on the rocker arm 54 will move into engagement with the roller 53 and impart a sudden tripping movement to the lever 47 to quickly move the trigger valve 40 to open position to permit the ejection of a fuel charge to the injector nozzle through the passages 34 and 43 and recess 42 of the trigger valve. At the same time, or while the valve is at the inner end of its stroke, the oil supply passages 74 and 75 to the timing chamber 71 are opened through the communicating recess 76 in the trigger valve. If the stroke of the engine pistons is normal and the bleed valve 78 is adjusted so that the release from the passage 75 equals the quantity of oil supplied through said passage to the chamber 71 at each engine stroke, then there will be no movement of the timing piston 70 and the injection timing will continue proper for normal stroke running of the engine. If, however, the engine piston stroke is lengthened, the time roller 53 is in contact with cam 55 is initially increased in proportion to the time the roller is on the concentric portion 55a of the rocker arm 54, and therefore the time during which oil enters chambers 71 constitutes a longer portion of the entire stroke, and more oil enters chamber 71 than escapes during each stroke for a time. This results in outward movement of timing piston 70 and consequent downward movement of fulcrum 48, resulting in a later contact of cam 55 with roller 53 and consequent later opening of the inlet into chamber 71. This continues until once more the amount of oil entering chamber 71 just equals that escaping during each stroke.

If the stroke is shortened, the reverse action takes place, plunger 70 moving inward until once more as much oil enters chamber 71 at each stroke as escapes therefrom during that stroke.

In the construction thus far described, the oil entering chamber 71, while the trigger plunger

is in its inner position, is under constant pressure, and the bleed passage is constant. If the pressure of spring 72 was constant, the result would be that the time during which oil entered the chamber 71 would always be in the same ratio to the total time while the engine maintained a constant speed and length of stroke, regardless of the actual speed or length of stroke. As a consequence, the interval of time between the start of fuel injection and the end of the compression stroke would be in a constant ratio to the total time of engine piston reciprocation.

Since spring 72 presents increasing resistance to outward movement of timing piston 70, lengthening the stroke and consequent outward movement of piston 70 results in some increase in pressure in chamber 71, with consequent increase in the rate of bleeding because of increased differential of pressure on the two sides of the bleed valve, and with decrease in the rate of entrance of oil from passage 19 because of decrease in differential pressure between passage 19 and chamber 71. This differential may be increased or decreased by shortening or lengthening spring 72, or may be completely eliminated by substituting for spring 72 a constant pressure device.

If desired, the fuel injection may be modified by adjusting the bleed valve so that the interval between fuel injection and the end of the compression stroke will vary in proportion to the time of the entire engine piston reciprocation in the desired manner.

For example, there is shown in Fig. 7 a device by which the bleed valve is automatically opened in response to increased engine speed and consequent increased peak pressures on the compression stroke. In this construction valve 77a is shown directly connected to piston 79 in chamber 80 and piston 81 in chamber 82. Piston 81 and valve 77a are pressed in valve-closing direction by spring 83 compressed between piston 81 and an adjustable stop 84. Chamber 82 is connected to the rebounce chamber R of the engine by passage 85 controlled by check valve 86, and chamber 80 is similarly connected to the compression chamber C of the engine by passage 87 controlled by check valve 88. Passage 85 has a branch 89 controlled by a bleed valve 90, and passage 87 has a branch 91 controlled by a bleed valve 92. Pistons 79 and 81 are preferably proportioned to each other in the same way as the compression chamber is proportioned to the rebounce chamber.

It will be seen that compressed gases will enter chambers 80 and 82 during the compression stroke of the engine, and will escape constantly through the bleed valves. With increased stroke and higher compression, the pressures in chambers 80 and 82 increase and the pistons move against spring 83 and increase the leakage past valve 77a. This increase in the rate of leakage results in a reduction of pressure in chamber 71 and an advance in the time of fuel injection, until the relative duration of the connection between passages 75 and 19 is increased sufficiently to make the introduction of oil into chamber 71 equal the increased leakage.

It will be seen that the effect of the automatic control just described is in the opposite direction from that of the increasing pressure of spring 72 as it is compressed, and by proper adjustment it may be made to first counterbalance the effect of the variation in pressure of the spring or to only partially overcome it or to overcompensate and give a net result in the opposite direction. By

these means the automatic timing of fuel injection may be adjusted to secure that injection, not only at the desired time for one length of stroke, but also to automatically time the fuel injection to exactly the same proportional point for a longer or shorter stroke, or for a relatively earlier or later injection, as preferred, for a relative increase or decrease in engine speed.

Turning eccentric 51 advances or retards the fuel injection for a given position of timing piston 70, and hand adjustment of the eccentric may be employed for this purpose.

In the construction shown in Fig. 8, there is shown automatic means for adjusting eccentric 51a. This means comprises a gear 93, securely fastened to the eccentric shaft, and a rack 94 in mesh with the gear. The rack is attached to a piston 95 in a cylinder 96, and the rack rod is extended upward to form a piston 97 in cylinder 98. A spring 99 urges the pistons upward. Piston 95 is urged downward by compressed gases coming through passage 100 past check valve 101 from the rebounce chamber of the engine, and piston 97 is urged downward by gases coming through passage 102 past check valve 103 from the compression chamber of the engine. A bleed passage 104 from cylinder 96 is controlled by valve 105, and a bleed passage 106 from cylinder 98 is controlled by a valve 107. The peak pressures in the rebounce and compression chambers increase as the speed of the engine increases, and this increases the pressures in cylinders 96 and 98, lowers the pistons and rack, turns the eccentric in a clockwise direction, and thereby raises roller 52 and advances the time of fuel injection. A decrease in engine speed works in the opposite way. In this way, the time of fuel injection may be advanced as the speed increases and retarded as the speed decreases, if that is desired for any reason.

When the device shown in Fig. 8 is employed with the timing piston 70 that piston will obviously move in or out until the bleed through valve 77 balances the quantity of each intake. However, as the eccentric 51a automatically adjusts the injection timing, in response to the pressures existing in chambers 96 and 98 as previously explained, the operation of this combination tends to time injection relative to speed and to also maintain the proper relation between injection and stroke termination.

With any increase of speed at a given stroke the charging period for chamber 71 in Fig. 1 is shortened and consequently a reduction in flow results, thus allowing piston 70 to drift inward, advancing injection. As previously explained, the device shown in Fig. 8 provides the same action. However, if the stroke should increase with an increase of speed, which is the normal reaction, the piston 70 would be held relatively stationary and no timing advance would occur. Therefore, the device shown in Fig. 8 would be the means for controlling injection relative to engine speed, while the piston 70 reacted only to variations in stroke.

It will be seen that by proper selection, combination and adjustment of the automatic means described, any desired relation of the timing of the fuel injection to the end of the compression stroke can be established and automatically maintained throughout variations in the length of stroke and speed of operation.

I wish it understood that my invention is not limited to any specific construction, arrangement or form of the parts, as it is capable of numer-

ous modifications and changes without departing from the spirit of the claims.

Having thus described my invention, what I claim as new, and desire to secure by United States Letters Patent, is:

1. In an internal combustion engine of the free piston type having a piston synchronizing means, and a fuel injection nozzle with a fuel supply passage thereo, mechanism operable to effect a timed fuel charge injection through said passage to the nozzle, said mechanism including a control valve for said passage and normally standing in closed position, and mechanical means connecting said synchronizing means and valve and operable by the former to momentarily move the valve to open position when the pistons reach a given point, and means controlled by the length of stroke of the pistons for determining the position of said given point for succeeding strokes.

2. In an internal combustion engine of the free piston type having a piston synchronizing means and a fuel injection nozzle with a fuel supply passage thereto, mechanism operable to effect a timed fuel charge injection through said passage to the nozzle, said mechanism including a control valve for said passage, means connecting said valve and the synchronizing means and operable to momentarily open said valve means when the pistons reach a given position to permit a fuel charge injection, and timing means cooperating with said connecting means and automatically operable to gradually move said given position towards or from the end position of the piston as the stroke of the piston lengthens or shortens, respectively.

3. In an internal combustion engine of the free piston type having synchronizing means for the engine pistons and a fuel injection nozzle with a fuel supply passage thereto, a normally closed control valve for said passage, mechanical operating means for the valve connected to and actuated by said synchronizing means to move the valve to open said passage in predetermined timed relation to the end of the compression strokes of the pistons for normal running and to increase the length of the open period of the valve when the stroke length of the pistons is increased, and injection timing means for said connecting means including a fluid pressure supply controlled by said valve and which supply is increased in volume by an increase in the opening period of the valve, said timing means being responsive to said pressure volume increase to act on said connecting means to vary the valve opening period to maintain a substantial constant predetermined relation of the fuel injection operation to the piston movement when the piston strokes are lengthened from normal.

4. In an internal combustion engine of the free piston type having synchronizing means for the engine pistons and a fuel injection nozzle with a fuel supply passage thereto, a control valve for said nozzle, means operable to hold the valve in closed position for a major portion of the piston stroke movements and connected to and operable by said synchronizing means to open the valve at a predetermined point in a normal compression stroke of the pistons and to increase the open period of the valve upon an increase in the length of the piston strokes, said operating means being adjustable to maintain a substantially constant relationship of the fuel charge injection to the termini of the compression strokes of the pistons, and timing means including a fluid pressure supply controlled by said valve and which is

increased in volume by an increase in the open period of the valve, said timing means being responsive to said pressure volume increase to effect said adjustment to the operating means.

5. In an internal combustion engine of the free piston type having a synchronizing means for the engine pistons and a fuel injection nozzle with a fuel supply passage thereto, a control valve for said passage, means operable to hold the valve in closed position during a predetermined portion of the piston strokes and to open it to permit a fuel charge injection when the pistons are each at a predetermined point in a compression stroke near the end thereof, said operating means including a reciprocably movable cam and a lever actuated thereby to open the valve at a predetermined point in a compression stroke of the pistons and to increase the length of the open period when the piston stroke length is increased from normal, and timing means including a fluid pressure supply controlled by said valve and which is increased in volume by an increase in the open period of the valve, said timing means being responsive to said pressure volume increase to effect a relative adjustment of said lever and cam to maintain the fuel injection timing in predetermined relation to the ends of the compression strokes of the pistons.

6. In an internal combustion engine of the free piston type having a piston synchronizing means and a fuel injection nozzle with a fuel supply passage thereto, a normally closed control valve for said passage, a mechanism connecting said synchronizing means and valve and operable by the former to move the valve to open said passage when the pistons are in predetermined spaced relation to the ends of their compression strokes, said mechanism including a reciprocatory cam member whose movements duplicate on a reduced scale the piston movements and a connection between said member and valve operable by the cam to open the valve when the cam reaches a predetermined point in its travel, and means controlled by the length of the piston stroke to determine said point.

7. In an internal combustion engine of the free piston type having a piston synchronizing means and a fuel injection nozzle with a fuel supply passage thereto, a control valve for said passage, a mechanism connecting said synchronizing means and valve and operable to move the valve to open position when the pistons, during a compression stroke, have reached a predetermined relationship to such stroke ends, said mechanism including a reciprocatory cam member simulating the piston stroke movements and a lever connecting the cam and the valve, adjustable fulcrum means for said lever, and means automatically operable to adjust the lever fulcrum in accordance with a change in the engine piston stroke length from normal whereby the valve opening timing maintains a substantially constant predetermined relation to the end of the piston compression stroke irrespective of the length of such strokes.

8. An arrangement as called for in claim 7 wherein said fulcrum adjusting means includes a bell-crank lever carrying the fulcrum together with a spring and an opposing fluid pressure means to effect said adjustment.

9. In an internal combustion engine of the free piston type having a piston synchronizing means and a fuel injection nozzle with a fuel supply passage thereto, a control valve for said passage, a rocker member having an arcuate surface concentric to its rocking axis and a cam at an end

of such surface, means for rocking said member in synchronized relation to the engine piston strokes, a plunger operable by said rocker member during each compression stroke of the pistons to create a fuel charge under pressure in said passage when the passage is closed, and means coacting with said arcuate surface and cam and actuated by the latter to move the valve to open said passage when the pistons, on a compression stroke, are in predetermined relation to the stroke ends.

10. In an internal combustion engine of the free piston type having piston synchronizing means and a fuel injection nozzle with a fuel supply passage thereto, a control valve normally closing said passage, a rocker member having an arcuate surface concentric to its rocking axis and a cam at an end of such surface, means for rocking said member in synchronized relation to the engine piston strokes and varying such rocking in accordance with any change in the length of the piston strokes, a plunger operable by said rocker member during each compression stroke of the pistons to create a fuel charge under pressure in said passage when the passage is closed, and means coacting with said arcuate surface and cam and actuated by the latter to move the valve to open said passage when the pistons reach a pretermined spacing with respect to their compression stroke ends, and means operable to vary the time of engagement of said cam coacting means with the cam in accordance with a change in the piston stroke length to maintain a substantially constant relationship of valve opening to the ends of the piston compression strokes irrespective of the length of the strokes.

11. In an internal combustion engine of the free piston type having a piston synchronizing means and a fuel injection nozzle with a fuel supply passage thereto, a control valve for said passage, means connected to and actuated by said synchronizing means to move said valve to open said passage when the pistons are in predetermined spaced relation to the ends of their compression strokes, a fuel pump operable by said connecting means to create a fuel charge in said passage during each compression stroke of the piston and before the opening of said valve, and means yieldingly operable to forcefully eject a fuel charge from said passage when open.

12. In an internal combustion engine of the free piston type having a piston synchronizing means and a fuel injection nozzle with a fuel supply passage thereto, a control valve for said passage, means connected to and actuated by said synchronizing means to move said valve to open said passage in predetermined spaced relation to the end of the piston compression stroke, a pump plunger operable by said connecting means to pump a fuel charge into said passage during a compression stroke of the pistons and before an opening of said valve, means resisting a pumping stroke of the plunger and operable to return it to starting position, means operable to resist the compression of a charge in said passage by the pump plunger and to forcefully eject the charge therefrom to the nozzle when said passage is open, means forming a relief passage from said first passage around the valve and controlled by said last means whereby the relief passage is closed to the fuel passage during the compressing of a charge in the fuel passage and its forceful ejection therefrom and is open to the fuel passage after the ejection of a charge, said pump plunger cooperating with said relief passage to close it except when the pump plunger is at substantially the inner end of its fuel charge compressing movement.

13. In an internal combustion engine having a free piston, a fuel injection nozzle with a fuel passage thereto and a valve in said passage, a member connected to and reciprocated by and with the piston, means actuated by said member for opening the valve and comprising automatic means to bring said opening into predetermined relation to the end of the compression stroke of the piston when the length of the stroke is varied.

14. In an internal combustion engine having a free piston, a fuel injection nozzle having a passage for fuel to the nozzle and a valve in the passage, a member reciprocating synchronously with the piston, connections from said member to the valve opening the valve when the member reaches a certain point in its travel, said connections comprising adjusting means for opening the valve at an earlier or later point in the travel of said member, and means governed by the length of stroke of the piston for actuating said adjusting means.

15. In an internal combustion engine having a free piston and a fuel injection nozzle with a fuel passage thereto and a valve controlling the passage, a member reciprocating in synchronism with the piston, means controlled by said member and opening the valve when the member reaches a predetermined point in its travel, and means actuated by the length of the reciprocation of said member to automatically adjust the timing of the valve opening when the stroke of the piston is changed in length to bring the valve opening into predetermined relation with the end of the compression stroke of the piston.

16. In an internal combustion engine having a free piston and a fuel injection nozzle with a fuel passage thereto and a valve controlling the passage, a member reciprocating in synchronism with the piston, connections mechanically operated by said member and opening the valve when said member reaches a predetermined position, and automatic means controlled by the length of the reciprocation of the member for adjusting the connections to bring the point in the travel of said member at which the valve is opened into predetermined relation with the end of the compression stroke of the piston when the length of that stroke changes.

17. In an internal combustion engine having a free piston and a fuel injection nozzle with a fuel passage thereto and a valve controlling the passage, a member reciprocating in sychronism with the piston, connections mechanically operated by said member and opening the valve when said member reaches a predetermined position, a cylinder, a piston in the cylinder under substantially constant pressure in one direction, a passage containing liquid under constant pressure and connected to the cylinder to urge the piston in the other direction, a valve in the last said passage opening when the fuel valve is opened, a bleeder passage constantly open from said cylinder, and connections from the piston adjusting the connections from said member to the fuel valve to bring the opening of the fuel valve at a later point in the travel of said member as the piston moves in response to said fluid pressure and vice versa when the piston moves in response to said substantially constant pressure.

18. In an internal combustion engine having a free piston, a fuel injection nozzle having a

passage for fuel to the nozzle and a valve in the passage, a member reciprocated by and synchronously with the piston, mechanical connections actuated by said member and opening said valve when said member reaches a certain point in its travel, said connections comprising a lever, and means controlled by the length of stroke of said member for moving the fulcrum of the lever and thereby adjusting the point in the travel of said member where fuel injection takes place.

19. In an internal combustion engine having a free piston and means to inject fuel, a timing device for timing the injection of the fuel comprising a member providing a cavity for fluid, means for introducing fluid into the cavity in increased amounts when the stroke of the piston is lengthened and in decreased amounts when the stroke of the piston is shortened, a continuously open bleed passage from the cavity, and means bringing the fuel injection at a later point in the travel of the piston on its compression stroke when fluid in the cavity is increased and at an earlier point when the fluid in the cavity is decreased.

20. An internal combustion engine of the free piston type comprising piston synchronizing means, fuel injection means, mechanical connection from the synchronizing means to the fuel injection means initiating the fuel injection when the pistons approach the end of their compression stroke, and automatic means operated by the length of travel of the pistons after fuel injection starts until the compression strokes end, to adjust said connections and bring the start of fuel injection later in the piston travel after a long stroke and earlier after a short stroke.

21. Apparatus in accordance with claim 20 and said automatic means comprising a cylinder and

means to admit fluid under pressure into the cylinder from the time fuel injection starts until the end of the combustion stroke is reached.

22. An internal combustion engine of the free piston type comprising a piston synchronizing means, a normally closed valve controlling fuel injection, mechanical connection from the synchronizing means to the valve opening the valve in a fixed point in the travel of the pistons on their compression stroke and closing said valve when the pistons reach said point on their working stroke, and timing means comprising a timing cylinder, means admitting fluid under pressure into the timing cylinder while said valve is open, a constant bleed outlet from said timing cylinder, and means operated by the fluid in the timing cylinder adjusting said connection to move said point towards the end of the compression stroke when fluid in the timing cylinder increases and to move said point away from the end of the compression stroke when the fluid in the timing cylinder decreases.

FRANK M. LEWIS.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,596,194	Lang	Aug. 17, 1926
Re. 18,429	Peterson	Apr. 19, 1932
2,025,362	Starr	Dec. 24, 1935
2,083,680	Anderson et al.	June 15, 1937
2,090,709	Steiner	Aug. 24, 1937
2,182,063	Steiner	Dec. 5, 1939
2,189,497	Pescara	Feb. 6, 1940
2,344,058	Pescara	Mar. 14, 1944