

Oct. 21, 1969

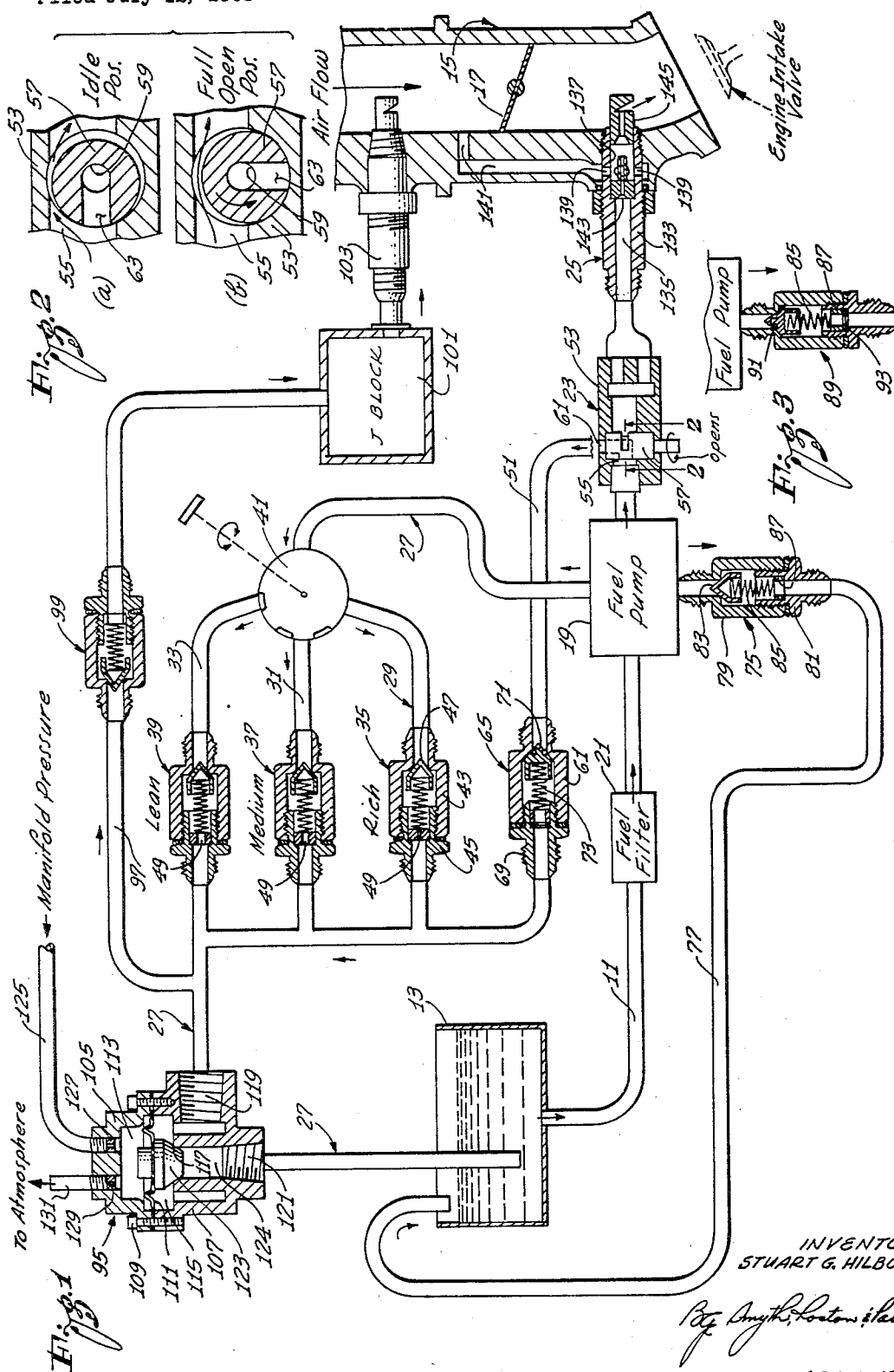
S. G. HILBORN

3,473,523

FUEL INJECTION SYSTEM

Filed July 12, 1968

3 Sheets-Sheet 1



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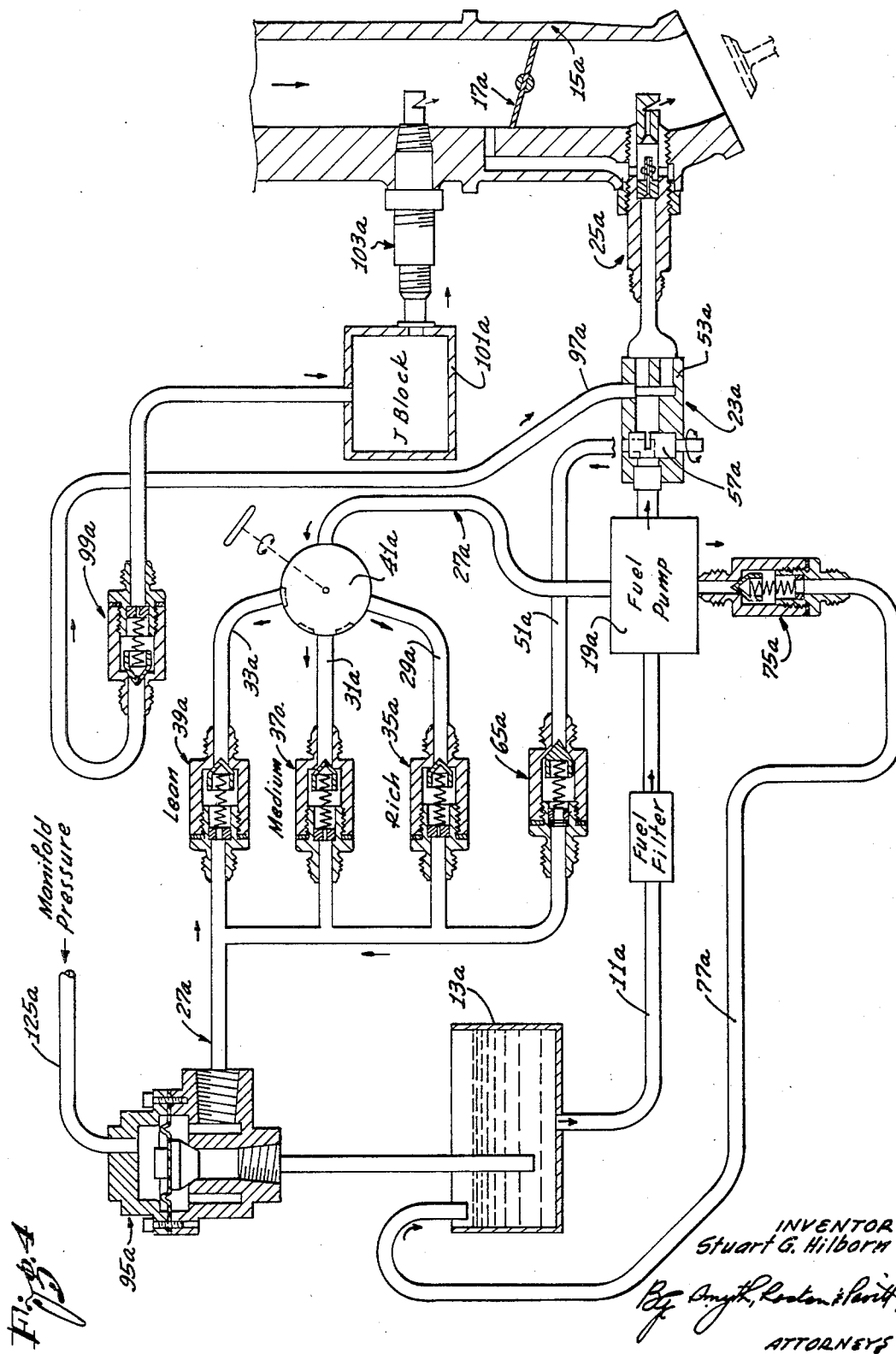
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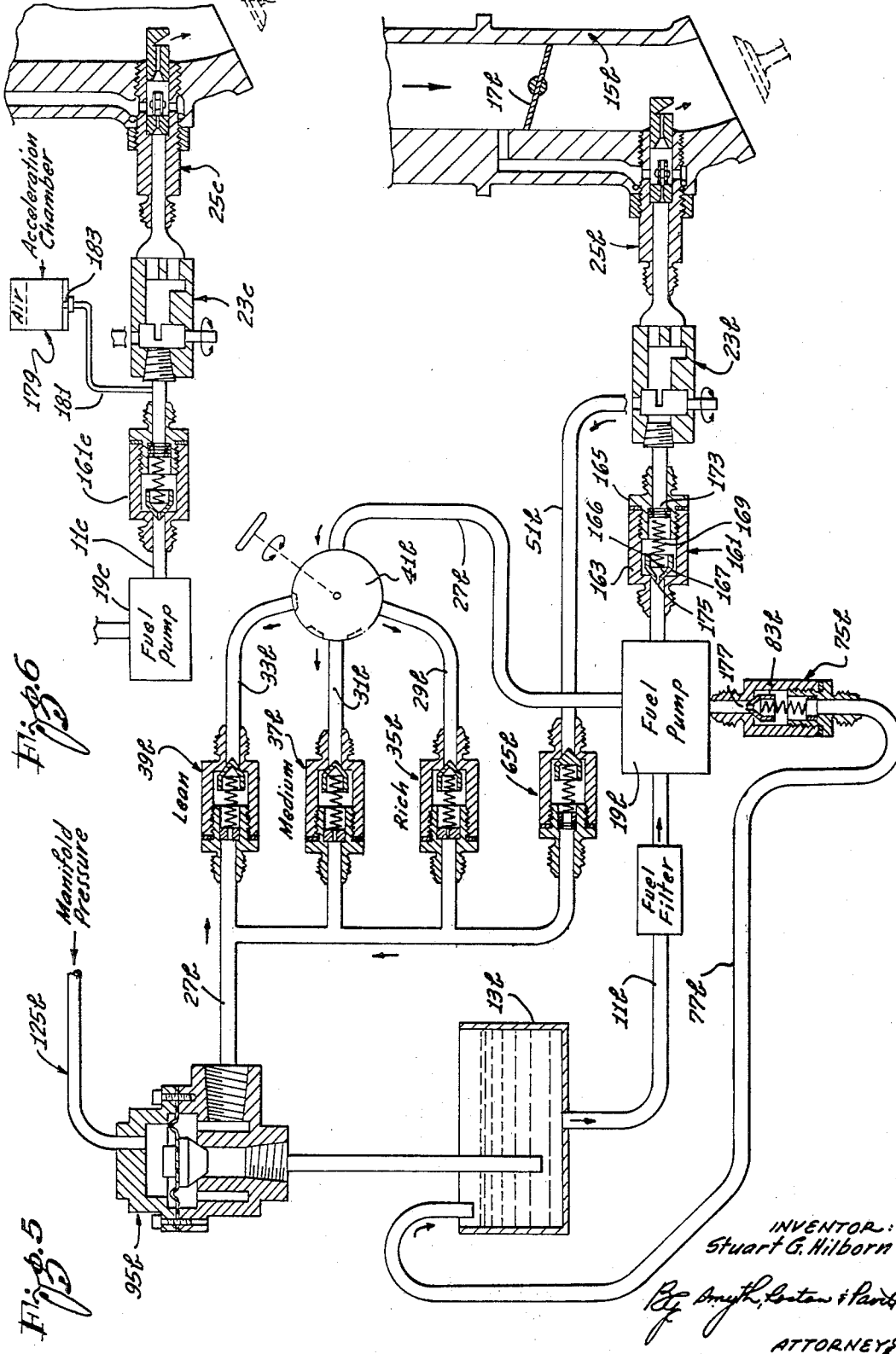
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3,473,523

FUEL INJECTION SYSTEM

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Continuation-in-part of application Ser. No. 545,748, Apr. 27, 1966. This application July 12, 1968, Ser. No. 754,752

Int. Cl. F02m 39/00, 7/00; F02d 1/04

U.S. Cl. 123—139

51 Claims

ABSTRACT OF THE DISCLOSURE

This disclosure describes a fuel injection system which includes supply conduit means for interconnecting a fuel storage tank and the inlet manifold of an engine, a fuel pump for pumping fuel through the supply conduit means, and a metering valve for controlling the amount of fluid pumped through the conduit means to the engine. A series of bypasses and feedback conduits are provided for feeding some of the fuel back to a location on the intake side of the fuel pump to improve engine performance.

This application is a continuation-in-part of application Ser. No. 545,748, now abandoned, filed Apr. 27, 1966. This invention relates to a fuel injection system and more particularly to a fuel injection system particularly adapted for use with automobile racing engines.

The fuel requirements of an automobile racing engine vary rapidly over a wide range. For example, the speed of a supercharged racing engine may vary from 1000 r.p.m. to over 10,000 r.p.m. in a few seconds. The throttle position may change from closed, to fully open, to partly open, and back to fully open within seconds. Each slight variation of throttle position and of engine speed will produce a corresponding fluctuation in manifold pressure which might range, for example, from zero to 120 inches Hg positive boost, then down to 25 inches of Hg vacuum. These extreme changes in manifold pressure may occur in just a few seconds as during an acceleration or "drag" race in which a racing vehicle may accelerate from zero to 200 miles per hour in less than eight seconds.

Each change in engine r.p.m. or air flow to the engine requires a corresponding and accurately controlled change in fuel flow. If the fuel injection system fails to produce these changes or fails to produce them accurately and without excessive time delay, power is lost, engine performance is poor, and damage to the engine may occur.

Racing engines must be capable of using a variety of fuels such as gasoline, methanol and nitromethane. When nitromethane is used, the required fuel flow may be 700% greater than when gasoline is used. Accordingly, it is extremely important that the fuel injection system be capable of quickly altering the fuel-air mixture to accommodate a wide variety of fuels.

Generally, prior art fuel injection systems vary the amount of fuel supplied to the engine in response to various engine conditions. However, the prior art fuel injection systems are generally unsatisfactory and not sufficiently flexible to efficiently operate over the wide range of fuels, engine r.p.m., and engine air flows required in the racing engine.

The fuel injection system of this invention quickly and accurately changes the rate of fuel flow to the engine in response to a large number of operating conditions. In particular, excessive richness is avoided during deceleration and during periods of very high engine speed. The fuel injection system can be adapted for different fuels by merely adjusting a selector valve. All of these features are present during supercharged and unsupercharged op-

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eration. For supercharged operation auxiliary injection means automatically supplies additional fuel to the engine.

The concepts of the present invention can be advantageously embodied in a system which includes a conduit for interconnecting a fuel tank and the inlet manifold of the engine, a fuel pump for pumping fuel through the conduit to the inlet manifold and a metering valve for controlling the amount of fuel pumped through the conduit to the inlet manifold. Excess fuel or fuel that is supplied by the fuel pump and is not required for unsupercharged engine operation or during other phases of engine operation is returned through various feedback conduits to the fuel tank.

To allow the engine to utilize different fuels or various fuel air mixtures of the same fuel, the fuel injection system accurately controls the amount of fuel that is returned to the fuel tank through one of the feedback conduits. This is preferably accomplished by providing a primary bypass which includes primary bypass passage means which provides a plurality of feedback paths arranged in parallel and a plurality of mixture control valves connected, respectively to the parallel feedback paths. A selector valve is provided for selectively allowing fluid to flow through one of the mixture control valves and its associated feedback path while blocking fuel flow through the other mixture control valves. Each of the mixture control valves has a different size flow orifice therein and hence a different maximum flow rate. Thus, by appropriate adjustment of the selector valve different rates of feedback and different flow rates of fuel to the engine are rapidly and accurately obtained. The selector valve can be rapidly moved to the desired position so that the fuel-air mixture is quickly and easily varied a predetermined amount.

The fuel injection system as described above is operable whether or not the engine is supercharged. A primary feature of this invention is adapting this fuel injection system for supercharged operation. This may be accomplished by providing auxiliary injection means, which is responsive to the pressure in the manifold reaching a predetermined value such as might be caused by supercharging, for supplying at least a portion of the excess fuel from the feedback conduit to the engine.

It is important that the auxiliary injection means be sensitive to fluctuations in supercharger pressure and fuel pressure. Accordingly, the auxiliary injection means includes a return valve in the feedback conduit for controlling the amount of excess fuel returned to the tank and a return valve operator which is responsive to the pressures in the inlet manifold and to the fuel pressure in the feedback conduit for controlling the opening and closing of the return valve. More particularly, the valve operator in a preferred form includes a housing, a movable diaphragm dividing the housing into first and second chambers, and separate conduits for connecting the first and second chamber to the inlet manifold and to the feedback conduit, respectively. Thus, the pressure of the fuel in the feedback conduit acts on one side of the diaphragm and the pressure in the inlet manifold acts on the other side of the diaphragm to control movements of the diaphragm and opening and closing of the return valve.

In one form of the invention the first chamber, which is connected to the inlet manifold is vented to the atmosphere through a small diameter vent, and the flow of air from the inlet manifold into the first chamber is controlled by a relatively small diameter jet. By varying the size of the vent opening and/or the inlet jet, the amount that the return valve is opened in response to a given set of pressure conditions can be varied. This means that the amount of fuel that is fed through the auxiliary injection

system to the engine is likewise variable. Of course, only the fuel that is excess and unneeded for unsupercharged operation is fed by the auxiliary injection system to the engine.

In another form of the invention the first chamber is not vented and the jet between the inlet manifold and the first chamber is removed. This makes the return valve immediately responsive to changes in manifold pressure.

In order to obtain an optimum acceleration range, most racing engines are required to operate at speeds in excess of the speed at which the horsepower is maximum. As engine speed increases beyond the speed at which horsepower is maximum, the total air flow to the engine decreases. However, the output of the fuel pump, which is driven by the engine, continues to increase. Accordingly, the fuel mixture supplied to the engine is excessively rich.

To eliminate this problem, the present invention employs a second feedback conduit leading from the discharge side of the fuel pump back to the fuel tank and a high-speed cutoff valve in this conduit. The high-speed cutoff valve, which may be of the relief valve type, is set to start opening at whatever fuel pressure is present in the pump just after exceeding the speed at which horsepower is maximum. Thus, as the engine speed exceeds the speed at which horsepower is maximum, the fuel pressure increases and the high-speed cutoff valve is automatically opened to prevent an increase in fuel flow to the engine. In an actual engine it may be desirable to set this valve to begin opening at a fuel pressure slightly under that which exists when horsepower is maximum to provide time for the valve to open. Thus, it may be said that the valve should open at approximately the speed at which horsepower is maximum. To provide smooth opening of the valve, the valve element should be provided with an orifice defining a leakage path for the fuel.

Another fuel injection problem is presented during deceleration. In this situation the throttle is suddenly closed and the metering valve is suddenly moved to the idle position. Because the fuel pump is driven by the engine, the output thereof continues at nearly maximum until the engine speed is reduced. During this period the fuel flow is high and the engine requirement is low, leaving only the primary bypass through the mixture control valves to return the excess fuel to the fuel tank. Under these circumstances the quantity of excess fuel greatly increases. Since the primary bypass will usually not be capable of returning all of the excess fuel to the tank under these conditions, the fuel pressure rises and this results in excessive richness of the fuel-air mixture.

The present invention eliminates this problem by providing a secondary bypass passage or feedback passage leading from the metering valve back to the fuel tank, the bypass being automatically opened in response to the metering valve approaching the idle position. More particularly, the metering valve preferably includes a housing having a flow passageway therethrough and a valve element in the flow passageway movable between a full open position and an idle position in which the flow passageway is at least partially blocked by the valve element. A passage extends through the valve element and communicates with the secondary bypass passage. The passage in the valve element is arranged to be blocked by the housing when the metering valve means is in the full open position and is in communication with the flow passageway when the valve element is in or near the idle position, the passage in the valve element is exposed to the fuel within the metering valve and at least a portion of such fuel flows through the secondary bypass back to the fuel tank. Thus, excessive richness during deceleration is eliminated. A similar condition is produced by cars racing from a standing start where a small throttle opening and fairly high r.p.m. exists. The secondary bypass prevents excessive richness at this time also.

Fuel is injected into the inlet manifold downstream of the throttle valve by a nozzle which is preferably of the air-

gap type. The air-gap type nozzles are vented to the upstream side of the throttle valve. The nozzle for injecting fuel fed by the auxiliary injection system are secured to the inlet manifold upstream from the throttle valve and are not of the air-gap type.

As indicated hereinabove, in one form of the invention, the return valve is not vented to the atmosphere to thereby improve the response of the engine fuel system to changes in manifold pressure. This also helps to provide a better air-fuel ratio at part throttle. To further improve the air-fuel ratio at part throttle, the present invention teaches that the fuel flow to the auxiliary fuel injection nozzle should be a function not only of inlet manifold pressure but also of metering valve position. This may be accomplished by interconnecting the auxiliary fuel injection conduit means to the supply conduit downstream of the metering valve.

An engine will operate most efficiently at a given fuel-air ratio and fuel flow should be proportional to air flow over a wide range of operating conditions. Theoretically, air flow and fuel flow should be proportional to engine r.p.m. In actual practice, however, factors such as cam shaft timing, manifold pressure, and volumetric efficiency come into operation to such an extent that air flow is not proportional to r.p.m., but the fuel pump output is. A significant problem in designing a fuel system, particularly for a racing engine, is to tailor the fuel flow rate so that fuel will be proportional to air flow under a wide range of operating conditions. Tailoring of a fuel flow curve for a supercharged engine is particularly difficult because of the additional fuel required for supercharged or blown operation. One way to accomplish this is to use a dual set of nozzles, i.e. a main nozzle and an auxiliary nozzle for each cylinder. With this system, the main nozzle is sized to provide adequate fuel for unblown operation and the auxiliary nozzle is sized to provide whatever amount of additional fuel is required for supercharged operation.

According to another embodiment of the present invention, the auxiliary nozzle can be eliminated and the fuel flow curve is accurately tailored over a wide range of operating conditions. This can be advantageously accomplished with modifier valve means which provides passage means for supplying fuel to the engine and an openable valve element for providing additional fuel flow to the engine. In a preferred embodiment, the passage means includes an orifice in the valve element to thereby provide a fuel flow path to the nozzle which remains open regardless of the position of the valve element. This orifice is preferably sized to provide sufficient fuel for unsupercharged operation and, if desired, for the initial portion of supercharged operation. The valve element is openable in response to the differential fuel pressure acting thereon to provide additional fuel flow to the engine. Preferably, the valve element opens at or shortly after supercharged operation has begun. The valve may be of the relief valve type with the spring pressure set to open at whatever fuel pressure exists when supercharged operation is begun.

The modifier valve can also be used in unsupercharged engines. Here the orifice is sized to provide sufficient fuel for idle and for the lower r.p.m. range and the valve then opens to supply the upper r.p.m. range. The shape of the fuel flow curve can thus be shaped to suit the engine requirements.

With this embodiment of the present invention, only the main nozzle is required and this nozzle must be sized to supply all of the fuel that is required for supercharged operation. Thus, the valve element causes a single nozzle system to function as though it were a dual nozzle system while accurately tailoring fuel supply. Various combinations of spring tension of this valve and orifice size in the primary bypass can be provided to achieve a fuel flow curve of almost any desired shape. Thus, the maximum horsepower possible can be obtained over a wide range of engine speeds. As used herein, blown operation or supercharged operation can be considered to exist when

any boost, i.e. pressure increase, occurs, in the inlet manifold of the engine as a result of supercharger operation.

As the valve element is opened by fuel pressure, it should preferably be positioned downstream of the pump. The valve is preferably located upstream of the metering valve but it could also be located on the downstream side of the metering valve.

It is normally desirable to enrich the fuel air mixture during acceleration and for a racing engine, it is important that such enrichment be promptly obtained. Accordingly, the present invention provides a secondary source of fuel under pressure which is responsive to opening of the throttle to provide additional fuel for acceleration.

To accomplish this, the present invention provides an acceleration chamber in communication with a location in the fuel supply conduit so that when the engine is operating at part throttle and the fuel pressure is relatively high, the acceleration chamber is filled or partially filled with fuel from the system. When the throttle is opened to accelerate the engine, the fuel pressure drops and this tends to draw fuel out of the acceleration chamber to provide momentary enrichment. By providing a suitably sized orifice in the conduit between the acceleration chamber and the fuel supply conduit, the rate and duration of fuel flow out of the acceleration chamber can be adjusted.

It is important that the acceleration chamber be connected into the fuel supply conduit at a location therein which is upstream of the metering valve. If such location were downstream the metering valve, the pressure at such location would be reduced when the metering valve closes and thus, the fuel in the acceleration chamber would drain into the engine during a part throttle condition.

Of course, in order that the acceleration chamber will be supplied with fuel under pressure, it should be located downstream of the pump. Furthermore, if a valve of the type described above is utilized in lieu of an auxiliary injection nozzle, the acceleration chamber should preferably be connected to the fuel supply conduit downstream thereof. If the acceleration were connected to the fuel supply conduit upstream of this valve, the fuel pressure would bleed off through the primary bypass during a part throttle condition. Even if such bleed off did not occur, the fuel would encounter additional resistance in passing through the valve.

The invention, both as to its organization and method of operation, together with further features and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing in which:

FIG. 1 is a diagrammatic illustration of one form of a fuel injection system constructed in accordance with the teachings of this invention with many of the components thereof being shown in longitudinal section;

FIGS. 2a and 2b are enlarged fragmentary sectional views taken along line 2—2 in FIG. 1 and illustrating the idle position and the full open position, respectively, of the metering valve; and

FIG. 3 is a fragmentary view partially in section illustrating a modified high-speed cutoff valve.

FIG. 4 is a diagrammatic view partially in section of a second form of fuel injection system constructed in accordance with the teachings of this invention.

FIG. 5 is a diagrammatic illustration of a third form of fuel injection system constructed in accordance with the teachings of this invention with many of the components thereof being shown in longitudinal section.

FIG. 6 is a fragmentary diagrammatic view partially in section of a fourth form of fuel injection system constructed in accordance with the teachings of this invention.

Referring to the drawing and in particular FIG. 1 thereof, a conduit 11 interconnects a fuel tank 13 and an inlet manifold 15 of an engine (not shown). The engine is of the internal combustion type and one of the inlet manifolds 15 is provided for each of the several cylinders of the engine. The inlet manifold 15 has a throttle valve 17 therein which is controlled in the conventional manner.

A fuel pump 19, which is driven by the engine draws fuel from the tank 13 and pumps it through the conduit 11, a fuel filter 21, a metering valve 23, and an injector nozzle 25, which is preferably of the air-gap type to the inlet manifold 15. The injector nozzle 25 injects fuel into the inlet manifold 15 downstream of the throttle valve 17.

To permit the engine to burn various fuels and to permit a variation in fuel-air mixture, a primary bypass is provided for returning the excess fuel supplied by the fuel pump 19. The primary bypass includes a primary bypass conduit or feedback conduit 27 that interconnects the discharge side of the fuel pump 19 and the fuel tank 13. The primary bypass conduit 27 provides a plurality of parallel passageways 29, 31, 33 having mixture control valves 35, 37 and 39, respectively, therein. A selector valve 41 in the primary bypass conduit 27 selectively allows fuel to flow through one of the mixture control valves while blocking fuel flow from the conduit 27 to the tank 13 through the other of the mixture control valves. In the position illustrated, fuel can flow through the selector valve 41 and the mixture control 39, but cannot flow through the mixture control valves 35 and 37.

Each of the mixture control valves includes a body portion 43, a tubular nut portion 45 secured to the body portion, a valve element 47 spring biased to the closed position, and a flow control jet 49 retained in the nut portion. Because the valve elements 47 are spring biased, the mixture control valves function as check valves to prevent backflow toward the fuel pump. The maximum quantity of fuel that the mixture control valves can pass depends upon the size of the jet 49. The size of the openings through the jets 49 of the mixture control valves 35, 37 and 39 progressively increases so that the mixture control valve 39 will return a larger quantity of fuel to the tank 13 than the mixture control valve 35 and will accordingly provide a relatively lean fuel-air mixture to the engine. If a richer fuel-air mixture is desired, the selector valve 41 can be quickly and easily rotated to allow flow through either of the valves 35 and 37. Any suitable number of mixture control valves may be provided.

During deceleration, the throttle valve 17 is closed and the metering valve 23 is in the idle position. The fuel pump 19, which is driven by the engine, continues to pump fuel at a relatively high rate until the engine speed is reduced, thereby producing an excessive amount of fuel, only some of which can be returned to the tank 13 through the primary bypass. To return the remainder of the excess fuel, a secondary bypass conduit or feedback conduit 51 is provided for interconnecting the metering valve 23 with the conduit 27.

The metering valve 23 includes a housing 53 having a flow passageway 55 extending therethrough and a cylindrical eccentrically mounted valve element 57 mounted in the passageway. The valve element 57 is mounted for rotation about an axis which is generally transverse the longitudinal axis of the flow passageway 55. The valve element 57 is rotatable between a full open position (FIG. 2b) and an idle position (FIG. 2a). The valve element 57 has a passage 59 which communicates with the secondary bypass conduit 51 through a port 61 in the housing 53. The passage 59 has an inlet section 63 which is closed by the housing 53 when the valve is in the full open position (FIG. 2b) and is exposed within the flow passageway 55 when the valve is in the idle position (FIG. 2a). The inlet section 63 is arranged within the

valve element 57 to be exposed within the flow passage-way 55 as the valve element is rotated from the full open position toward the idle position. Thus, as the idle position is approached during deceleration the excess fuel supplied by the fuel pump 19 is returned through the secondary bypass conduit 51 and the conduit 27 to the fuel tank 13.

To maintain a minimum fuel pressure for idling operation of the engine, a check valve 65, which is operable at such minimum pressure is provided in the conduit 51. The check valve 65 is similar in construction to the valve 35 and includes a body portion 67, a tubular nut portion 69 threadedly received within the body portion, a valve element 71, and a spring 73 urging the valve element 71 to the closed position. The force of the spring 73 is selected to maintain a certain minimum fuel pressure in the conduit 11 for idling.

As explained hereinabove, operation of a racing engine at speeds in excess of the speeds at which the horsepower is maximum causes the fuel mixture to be excessively rich. To obviate this problem, a high-speed cutoff valve 75 is connected at its inlet end to the discharge side of the fuel pump 19 and at its outlet end to a feedback conduit 77 which leads directly to the fuel tank 13. The relief valve, which is usually provided on fuel pumps, is not required on the fuel pump 19. The valve 75 includes a body portion 79, a tubular threaded portion 81 threadedly received within the body portion, a movable valve element 83, a spring 85 urging the valve element to the closed position, and a tubular spacer 87 against which the spring 85 bears. The force exerted by the spring 85 is set so that the valve 75 will open at whatever fuel pressure exists when the speed at which horsepower is maximum is exceeded. The valve 75 limits fuel flow to the engine to the amount utilized by the engine when it is producing its maximum horsepower.

FIG. 3 illustrates a valve 89 of alternate construction which may be used in lieu of the valve 75. The valve 89 is identical to the valve 75 except for the addition of an O-ring 91 formed in a groove in the valve element and the addition of washers 93 behind the tubular spacer 87 for adjusting the force supplied by the spring 85 to the valve element.

The fuel injection system which has been described in detail thus far is usable with or without supercharging of the engine. An important feature of this invention is the provision of auxiliary injection means which is responsive to supercharging of the engine for supplying at least a portion of the excess fuel from the feedback conduits 27 and 51 to the engine. The auxiliary injection means includes a return valve 95 for controlling the amount of excess fuel returned to the tank 13, a conduit 97, a check valve 99, a junction block 101, and an auxiliary injector nozzle 103 secured to the inlet manifold 15 upstream of the throttle valve 17.

The return valve 95 includes two housing sections 105 and 107 secured together by threaded fasteners 109 to form a valve housing. A movable flexible diaphragm 111 is clamped between the housing sections 105 and 107 to divide the valve housing into a control chamber 113 and a fuel chamber 115. The housing section 107 defines an annular valve seat 117, an inlet 119 and an outlet 121. The diaphragm 111 carries a valve element 123 therewith which is operative to open and close a valve passage-way 124 extending between the inlet 119 and the outlet 121. The control chamber 113 is connected to the inlet manifold 15 downstream of the supercharger and either upstream or downstream of the throttle valve by a pressure-sensing conduit 125 and a small diameter jet 127. The control chamber 113 is vented to the atmosphere through an outlet jet 129 and a vent 131.

The check valve 99 may be identical to the valve 75 and will require a certain minimum fuel pressure to open. The junction block 101 serves as a plenum chamber for

supplying fuel to the auxiliary injectors 103, one of which is located in each of the inlet manifolds 15.

When the pressure in the inlet manifold is atmospheric or below, the excess fuel in the conduit 27 will force the diaphragm 111 and the valve element 123 upwardly to open the return valve 95 and allow all of the excess fuel to return to the tank 13. When the pressure in the inlet manifold increases, as when the supercharger is operating, the pressure on the upper side of the diaphragm 111 is sufficient to prevent or limit opening of the valve 95, in which case the excess fuel flows through the conduit 97, the check valve 99, the junction block 101, and the auxiliary injectors 103 to the inlet manifolds 15. Should supercharging of the engine be discontinued, the return valve 95 would automatically open to allow the excess fuel to be returned to the tank 31. The auxiliary injection system only uses fuel that the primary injection system, i.e., the system feeding the nozzles 25, has "declared" to be excess. Thus, only the excess fuel is supplied to the inlet manifold by the auxiliary injection system. The proportions of the excess fuel that are returned to the tank 13 and that are supplied to the injectors 103 may be varied by varying the size of the jets 127 and 129.

It is preferred that the nozzle 25 be of the air-gap type illustrated. The nozzle 25 includes a body 133 having an axial bore 135 and an axial counterbore 137 therein. The body 133 is threadedly connected to the inlet manifold 15 and the counterbore 137 is placed in communication with and receives air from the upstream side of the throttle valve 17 by a plurality of ports 139 in the body 133 and a passageway 141 in the inlet manifold 15. Thus, the air gap nozzle receives air from the upstream side of the throttle 17 when the throttle is closing or closed.

FIG. 4 shows a second embodiment of the invention which produces a better fuel-air ratio at part throttle and improves throttle response. The embodiment of FIG. 4 is identical to the embodiment of FIG. 1 except as specifically noted herein and corresponding parts are designated by corresponding reference characters followed by the letter *a*.

The embodiment of FIG. 4 has primary bypass means, secondary bypass means, and high-speed cutoff means which are identical to the corresponding portions described in connection with FIG. 1. FIG. 4 differs from FIG. 1 in that the return valve 95*a* thereof is not vented to atmosphere and the conduit 125*a* leading to the manifold 15*a* upstream from the throttle valve 17*a* does not have a jet or orifice 127 therein. With this arrangement, the valve 95*a* is immediately responsive to pressure changes in the manifold 15*a* upstream from the throttle valve 17*a* such as may be caused by the supercharger. This tends to improve the response of the fuel control system to changes in the manifold pressure.

The second difference between the systems of FIGS. 1 and 4 is that with the latter, the auxiliary injection nozzle 103*a* is supplied with fuel from a conduit 97*a* which is connected to the supply conduit 11*a* downstream from the valve element 57*a* of the metering valve 23*a*. In the embodiment illustrated in FIG. 4, the conduit 97*a* is connected to the housing 53*a* of the metering valve 23*a*.

With this arrangement, the manifold pressure 125*a* affects fuel flow to the auxiliary nozzle 103*a* in that it influences the amount of fuel that can return to the fuel tank 13*a* through the bypasses 51*a* and 27*a*. In addition, the position of the valve element 57*a* of the metering valve 23*a* controls the amount of fuel fed to the auxiliary injection nozzle 103*a*. With this arrangement the fuel which passes through the metering valve 23*a* is divided between the nozzles 103*a* and 25*a* in accordance with relatively fixed percentages. This construction results in improved acceleration and throttle response and a better fuel air-ratio at part throttle.

FIG. 5 illustrates a third embodiment of the present invention which is identical to the embodiment of FIG.

4 in every respect not specifically set forth herein. Portions of the fuel system of FIG. 5 corresponding to portions of the systems of FIGS. 1 and 4 are designated by corresponding reference numbers followed by the letter b.

The embodiment of FIG. 5 differs from the embodiment of FIG. 4 in that the former has no auxiliary injection nozzle and is provided with a modifier valve 161 which has no counterpart in the embodiments of FIGS. 1 and 4. The valve 161 includes housing sections 163 and 165 which are threadedly attached and which define a valve body having a flow passageway therethrough. The valve body defines a valve seat 166. The valve 161 also includes a valve element 167 movable axially between a closed position in which the valve element tightly engages the valve seat 166 and an open position in which the valve element is spaced axially from the valve seat to permit fuel flow therebetween. A spring 169 is provided for urging the valve element toward the closed position thereof and one or more spacers or washers 173 may be provided as desired for the purpose of varying the force exerted by the spring on the valve element. The valve element 167 has a small diameter fixed area orifice 175 extending through a central region thereof through which fuel can flow regardless of the position of the valve element.

In operation of the system shown in FIG. 5, the spring 169 normally retains the valve element 167 in the closed position thereof during unsupercharged operation of the engine. During this time fuel is supplied through the orifice 175 and the metering valve 23b to the fuel injection nozzle 25b. During this time, the fuel pressure acting on the left-hand face of the valve element 167 is insufficient to overcome the biasing force of the spring 169 and of the fuel pressure on the right-hand face of the valve element.

As engine speed increases it drives the fuel pump and the supercharger faster. Thus, the fuel pressure on the discharge side of the fuel pump and the air pressure provided by the supercharger increase in accordance with a predetermined relationship. The force exerted by the spring 169 is preferably selected so that the fuel pressure on the left-hand face of the valve element 167 will be just enough to lift the valve element off of the seat 166 at approximately the time that the supercharger is effective to produce any boost, i.e. pressure increases, in the manifold as a result of supercharger operation. If desired, however, the element 167 may be maintained on the valve seat 166 for the first portion of supercharged operation. Thus, it may be stated that the valve 167 preferably opens at approximately the instant that there is some pressure increase in the manifold as a result of supercharge operation.

The valve element 167 is lifted off of the seat 166 in an appropriate relationship to the increase of air supplied by the supercharger. By varying the spring tension, the size of the orifice 175, and the amount of fuel bypassed through the primary bypass 27b, a fuel flow curve of almost any shape can be produced. This enables the production of maximum horsepower in both the high and low speed ranges and also eliminates the need for the auxiliary injection nozzle. Of course, it is necessary that the main fuel nozzle 25b be sized so that they can supply all of the fuel required by the engine for supercharged operation.

Another difference between the embodiment of FIG. 5 and the embodiments of FIGS. 1-4 is that the high speed cutoff valve 75b has a valve element 83b in which a small diameter orifice 177 has been formed. With this construction, the high speed cutoff valve 75b is continuously operative to feed back a very small quantity of fuel. This causes the valve element 83b to open gradually and smoothly as the fuel pressure increases. It should be understood that the high speed cutoff valve of any of the embodiments of the invention described herein may be provided with an orifice in the valve element thereof

such as the orifice 177. When the high speed cutoff valve 75b is provided with the orifice 177, the high speed cutoff valve is preferably located on the upstream side of the metering valve to avoid back flow into the fuel line at part throttle.

FIG. 6 shows still another embodiment of the present invention which is identical to the embodiment shown in FIG. 5 except for the presence of an acceleration chamber 179. Portions of the embodiment of FIG. 6 corresponding to the embodiment of FIG. 5 are designated by corresponding reference characters followed by the letter c. The acceleration chamber 179 in the embodiment illustrated is in the form of a tank or container. Communication between the fuel supply conduit 11c and the acceleration chamber 179 is provided by an interconnecting conduit 181 which is connected to the conduit 11c intermediate the modifier valve 161c and the metering valve 23c. Fuel can flow through the conduit 181 in either direction between the conduit 11c and the acceleration chamber 179. A fixed area orifice 183 is provided at any suitable location in the conduit 181.

At part throttle, the metering valve 23c is at least partially closed so that the pressure of the fuel in the line 11c will ordinarily be sufficiently high to cause flow of fuel through the conduit 181 and the orifice 183 into the acceleration chamber 179. The acceleration chamber 179 is a closed chamber and as fuel is fed therein, the air in the chamber is compressed. When the throttle and metering valve 23c are opened to accelerate the engine, the pressure in the line 11c upstream of the metering valve 23c and downstream of the modifier valve 161c drops sufficiently so that there is a pressure differential between this point and the fuel within the acceleration chamber 179. Accordingly, the compressed air in the chamber 179 forces the fuel in the acceleration chamber through the orifice 183, the conduit 181 and the metering valve 23c to the engine. The rate and duration of fuel flow out of the chamber 179 can be controlled by appropriately sizing of the orifice 183. Thus, the fuel in the acceleration chamber 179 forms, in effect, a secondary supply of fuel under pressure which is automatically utilized in response to opening of the throttle.

It will be appreciated that if the line 181 would be joined to the conduit 11c downstream of the metering valve 23c, that closing of the metering valve might very well result in a low pressure condition downstream thereof which would cause drainage of the fuel in the acceleration chamber into the engine. For this reason, the conduit 181 should be joined to the conduit 11c upstream of the metering valve 23c. Similarly, if the conduit 181 would be joined to the conduit 11c upstream of the modifier valve 161c, the fuel in the acceleration chamber might bleed off toward the pump and even if this did not occur, the fuel would have to overcome the resistance afforded by the valve 161c. Accordingly, the location of the union between the conduits 11c and 181 illustrated in FIG. 6 is preferred. The acceleration chamber 179 shown in FIG. 6 can be utilized with any of the embodiments of the invention described herein.

Although exemplary embodiments of the invention have been shown and described, many changes, modifications, and substitutions may be made by one having ordinary skill in the art without necessarily departing from the spirit and scope of this invention.

I claim:

1. In a fuel injection system for supplying fuel from a tank to an engine wherein the engine has a supercharger and an inlet manifold for supplying air thereto, the combination of:

- a first fuel injection nozzle for injecting fuel into the engine;
- supply conduit means for interconnecting the tank and said first fuel injection nozzle;
- a fuel pump for pumping fuel from the tank through

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said supply conduit means and the first fuel injection nozzle;

metering valve means for controlling the amount of fuel pumped through said supply conduit means to said first fuel injection nozzle, said metering valve means having an idle position in which only a small quantity of fuel is supplied to the first fuel injection nozzle and a full open position in which a greater quantity of fuel is fed to the first fuel injection nozzle;

feedback conduit means for returning at least a portion of an excess fuel pumped by said fuel pump from said supply conduit means to a location on the intake side of said pump;

an auxiliary fuel injection nozzle for injecting fuel into the engine;

an auxiliary injection conduit means leading from a location in said feedback conduit means to said auxiliary fuel injection nozzle to supply fuel thereto; and

valve means in at least one of said auxiliary injection conduit and said feedback conduit responsive to the pressure in the inlet manifold reaching a predetermined value for supplying at least a portion of the excess fuel from said feedback conduit means through said auxiliary injection conduit means to said auxiliary fuel injection nozzle.

2. A combination as defined in claim 1 wherein said valve means is responsive to operation of the supercharger to supply fuel to said auxiliary injection nozzle.

3. In a fuel injection system for supplying fuel from a tank to an inlet manifold of an engine, the combination of:

conduit means for interconnecting the tank and the inlet manifold;

a fuel pump for pumping fuel through said conduit means from the tank to the inlet manifold;

means for driving the fuel pump at a speed which increases with an increase in engine speed whereby the rate of fuel pumped by the fuel pump increases with engine speed;

metering valve means for controlling the amount of fuel pumped through said conduit means to said inlet manifold;

feedback conduit means providing a passageway for returning at least a portion of any excess fuel supplied by said pump to a location on the intake side of the pump; and

a high-speed cutoff valve including a valve element movable between an open position in which fuel can flow through said cut-off valve and through the feedback conduit means to said location and a closed position in which no more than a relatively small quantity of fuel can flow through said cut-off valve, said valve element being movable to said open position in response to the engine exceeding approximately the speed at which horsepower is maximum for causing at least some of the excess fuel to return through said feedback conduit means at a rate which increases to pump delivery pressure.

4. A combination as defined in claim 3 wherein the fuel pressure downstream from said pump varies with increasing engine speed and said valve means is responsive to the fuel pressure existing just beyond the point where engine horsepower is maximum to cause sufficient quantities of the fuel to return through said feedback conduit means to prevent an increase in fuel flow to the engine.

5. A combination as defined in claim 3 including primary bypass passage means for returning a portion of the fuel supplied by said pump to the intake side of said fuel pump and adjustable means in said primary bypass passage means for controlling the rate of flow of fuel therethrough to thereby permit adjustment of the fuel air ratio.

6. A combination as defined in claim 3 including secondary bypass passage means leading from said supply

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conduit means on the discharge side of said fuel pump to a region in said system on the intake side of said fuel pump and means responsive to the metering valve means reducing the amount of fuel pumped through the metering valve means to said inlet manifold for increasing the maximum flow rate which can occur through said secondary bypass passage means.

7. A combination as defined in claim 3 wherein said valve means includes a valve element movable between open and closed positions to control the flow of fuel through said feedback conduit means, said valve element having a port therein through which small quantities of fuel can flow independently of the position of said valve element.

8. In a fuel injection system for supplying fuel from a tank to an inlet manifold of an engine, the combination of:

conduit means for interconnecting the tank and the inlet manifold;

a fuel pump for pumping fuel through said conduit means from the tank to the inlet manifold;

means for driving the fuel pump at a speed which increases with an increase in engine speed whereby the rate of fuel pumped by the fuel pump increases with engine speed;

metering valve means for controlling the amount of fuel pumped through said conduit means to said inlet manifold;

feedback conduit means providing a passageway for returning at least a portion of any excess fuel supplied by said pump to a location on the intake side of the pump;

valve means in said feedback conduit means for controlling the flow of fuel therethrough to the intake side of said pump; and

said valve means including a valve body defining a flow passageway therethrough with said flow passageway forming a portion of said feedback conduit means, a valve element movable in said flow passageway between an open position in which a substantial quantity of fuel can flow through said flow passageway and a closed position, and biasing means for urging said valve element toward said closed position, said valve element being movable to the open position against the force of said biasing means in response to the engine exceeding approximately the speed at which horsepower is maximum whereby at least some of the excess fuel can return through said flow passageway.

9. A combination as defined in claim 8 wherein said valve means includes leakage passage means for permitting some of the fuel to return through said feedback conduit means when said valve element is in said closed position.

10. In a fuel injection system for supplying fuel from a tank to an inlet manifold of an engine, the combination of:

conduit means for interconnecting the tank and the inlet manifold;

a fuel pump for pumping fuel through said conduit means from the tank to the inlet manifold;

a metering valve for controlling the amount of fuel pumped through said conduit means to the inlet manifold, said metering valve having a full open position in which maximum fuel flow to the inlet manifold may occur and an idle position in which a substantially lesser amount of fuel can flow through said metering valve to the inlet manifold;

bypass passage means for returning at least some of any excess fuel supplied by said pump from said conduit means to a location on the intake side of said pump; and

said metering valve including a valve housing having a flow passageway therethrough, a movable valve element in said flow passageway movable between a full open position in which said flow passageway

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is open and an idle position in which said flow passageway is at least partially blocked by said valve element, passage means extending through said valve element and communicating with said bypass passage means, means for blocking said passage means when said metering valve is in said full open position, said passage means communicating with said flow passageway when said valve element is in said idle position.

11. In a fuel injection system for supplying fuel from a tank to an engine wherein the engine has a supercharger and an inlet manifold with a throttle valve therein downstream of the supercharger, the combination of:

nozzle means for injecting fuel into the inlet manifold downstream of the throttle valve;

supply conduit means for interconnecting the tank and said nozzle means;

a fuel pump for pumping fuel from the tank through said supply conduit means and the nozzle means to the inlet manifold, said fuel pump being driven in synchronism with the engine;

a metering valve for controlling the amount of fluid pumped through said supply conduit means to said nozzle means;

a bypass for returning some of the fuel pumped by the pump to a location on the intake side of said pump;

selective metering means in said bypass to control the amount of fuel passing through said bypass; and means responsive to a predetermined positive pressure in said manifold upstream from the throttle valve to bleed fuel from the bypass downstream from said selective metering means into said inlet manifold to augment the fuel delivery to the inlet manifold.

12. In a fuel injection system for supplying fuel from a tank to an inlet manifold of an engine, the combination of:

conduit means for interconnecting the tank and the inlet manifold;

a fuel pump for pumping fuel through said conduit means from the tank to the inlet manifold;

metering valve means for controlling the amount of fuel pumped through said conduit means to said inlet manifold;

feedback conduit means providing a plurality of parallel fuel passageways for returning any excess fuel supplied by the pump from said conduit means to a location on the intake side of the fuel pump;

each of said passageways having a mixture control valve therein for controlling the amount of fuel flow through its respective passageway, each of said mixture control valves having a different maximum flow rate to thereby provide different flow rates through each of said passageways; and

selector valve means for selectively allowing fuel to flow through one of said mixture control valves while blocking fuel flow from said conduit means to the tank through the other of said mixture control valves whereby the amount of fuel returning through said feedback conduit means can be rapidly changed.

13. A combination as defined in claim 12 wherein each of said mixture control valves includes a valve element, biasing means for urging the valve element toward a closed position and a fixed area orifice for controlling the maximum flow rate through such mixture control valve.

14. A combination as defined in claim 12 including a return valve in said feedback conduit means responsive to manifold pressure for providing additional control of the fuel flowing through the feedback conduit means.

15. In a fuel injection system for supplying fuel to an engine, the combination of:

nozzle means for injecting fuel into the engine;

supply conduit means for supplying fuel to the nozzle means;

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a fuel pump for pumping fuel through said supply conduit means to the nozzle means;

a metering valve for controlling the amount of fuel pumped through said supply conduit means to said nozzle means, said metering valve having a full open position in which maximum fuel flow therethrough may occur and an idle position in which a substantially lesser rate of fuel flow through the metering valve can occur;

primary bypass passage means leading from said supply conduit means on the discharge side of said fuel pump to a location in said system on the intake side of said fuel pump;

adjustable means in said primary bypass passage means for controlling the rate of flow of fuel therethrough to thereby permit adjustment of the fuel-air ratio;

secondary bypass passage means leading from said supply conduit means on the discharge side of said fuel pump to a region in such system on the intake side of said fuel pump; and

means responsive to said metering valve being in said full open position for at least substantially minimizing the maximum flow rate which can occur through said secondary bypass passage means and responsive to the metering valve being in said idle position for increasing the maximum flow rate which can occur through said secondary bypass passage means.

16. A combination as defined in claim 15 including return valve means, said primary and secondary bypass passage means leading to said return valve means, said return valve means being responsive to manifold pressure for exerting a control influence on the fuel flow through said primary bypass passage means.

17. A combination as defined in claim 15 wherein the rate of fuel flow pumped by said fuel pump increases with engine speed and including a high speed cutoff bypass passage means and high speed cutoff valve means responsive to engine speed exceeding approximately the speed at which horsepower is maximum for permitting at least some of the excess fuel to return through said high speed cutoff bypass passage means.

18. In a fuel injection system for supplying fuel from a tank to an engine wherein the engine has an inlet manifold for supplying air thereto, the combination of:

a first fuel injection nozzle for injecting fuel into the engine;

supply conduit means for interconnecting the tank and said first fuel injection nozzle;

a fuel pump for pumping fuel from the tank through said supply conduit means and the first fuel injection nozzle;

metering valve means having a movable valve element for controlling the amount of fuel pumped through said supply conduit means to said first fuel injection nozzle, said metering valve means having an idle position in which only a small quantity of fuel is supplied to the first fuel injection nozzle and a full open position in which a greater quantity of fuel is fed to the first fuel injection nozzle;

a region of said supply conduit means lying intermediate said valve element and the inlet manifold;

feedback conduit means for returning at least a portion of any excess fuel pumped by said fuel pump from said supply conduit means to a location on the intake side of said pump;

an auxiliary fuel injection nozzle for injecting fuel into the engine;

an auxiliary injection conduit means leading from at least one of said feedback conduit means and said region of said supply conduit means to said auxiliary fuel injection nozzle to supply fuel thereto; and

valve means in at least one of said auxiliary injection conduit means and said feedback conduit responsive to the pressure in the inlet manifold for supplying at least a portion of the excess fuel from said feedback

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conduit means through said auxiliary injection conduit means to said auxiliary fuel injection nozzle.

19. A combination as defined in claim 18 wherein said valve means is responsive to air pressure in the inlet manifold and fuel pressure in the feedback conduit means and includes a housing, a movable diaphragm dividing said housing into first and second chambers, means for connecting said first chamber to said inlet manifold, means for connecting said second chamber to said feedback conduit means to thereby cause movement of said diaphragm in response to predetermined variations in air pressure in the inlet manifold and fuel pressure in the feedback conduit means, and means for causing opening and closing of said valve means in response to movement of said diaphragm.

20. A combination as defined in claim 18 wherein said feedback conduit means includes a plurality of mixture control valves connected in parallel and selector valve means for selectively allowing fluid to flow through one of said mixture control valves while blocking fuel flow from said conduit means to the tank through the other of said mixture control valves, each of said mixture control valves having a different maximum flow rate whereby the feedback rate can be adjusted to compensate for different fuels.

21. A combination as defined in claim 18 wherein said feedback conduit means includes high-speed cutoff valve means responsive to the engine speed exceeding the speed at which horsepower is maximum for returning at least some of the excess fuel to a location on the intake side of said pump.

22. A combination as defined in claim 18 wherein said feedback conduit means includes secondary bypass means responsive to said metering valve means approaching said idle position for returning at least some of the excess fuel to a location on the intake side of said pump.

23. A combination as defined in claim 18 wherein the inlet manifold has a throttle valve therein, said first injection nozzle being secured to the inlet manifold downstream of the throttle valve and means are provided for providing communication between a location within said first injection nozzle and said inlet manifold upstream of the throttle valve regardless of the position of the throttle valve.

24. A combination as defined in claim 18 wherein said feedback conduit means includes primary bypass means for feeding back selectively variable quantities of excess fuel to a location on the intake side of said pump, high-speed cutoff valve means responsive to the engine speed exceeding the speed at which horsepower is maximum for feeding back at least some of the excess fuel, and secondary bypass means responsive to the metering valve means approaching said idle position for feeding back at least a portion of the excess fuel.

25. A combination as defined in claim 18 wherein the inlet manifold has a throttle valve and said first injection nozzle and said auxiliary injection nozzle are positioned on the downstream and upstream sides, respectively, of said throttle valve.

26. A combination as defined in claim 18 wherein said auxiliary injection conduit means leads from said region to the auxiliary fuel injection nozzle whereby the fuel flow through said auxiliary injection conduit means is a function of metering valve position and inlet manifold pressure.

27. In a fuel injection system for supplying fuel to an engine, the combination of:

- a nozzle for injecting fuel into the engine;
- supply conduit means for supplying fuel to the nozzle;
- a fuel pump for pumping fuel through said supply conduit means and the nozzle to the engine, said fuel pump being driven by the engine so that the pressure of the fuel pumped thereby increases with engine speed;
- a metering valve for controlling the amount of fluid

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pumped through said supply conduit means to said nozzle;

bypass means for bypassing some of the fuel pumped by the pump;

valve means arranged in series with said metering valve in said supply conduit means on the discharge side of said fuel pump responsive to a predetermined pressure condition in said supply conduit means for opening to permit said fuel to supply fuel to said nozzle through said supply conduit means; and means defining a fuel flow passage for supplying fuel from the fuel pump to said nozzle independently of said valve means and said predetermined pressure condition whereby the opening of said valve means provides additional fuel to the nozzle to thereby tailor the fuel flow to said nozzle.

28. A combination as defined in claim 27 including means responsive to opening the throttle of the engine for supplying additional quantities of fuel to said supply conduit means at a location therein downstream from said valve means.

29. In a fuel injection system for supplying fuel to an engine, the combination of:

- nozzle means for injecting fuel into the engine;
- supply conduit means for supplying fuel to the nozzle means;
- a fuel pump for pumping fuel through said supply conduit means and the nozzle means to the engine;
- a metering valve for controlling the amount of fuel pumped through said supply conduit means to said nozzle means;
- valve means in said supply conduit means for providing additional control of the fuel flow through said supply conduit means to the nozzle means;
- said valve means including a valve body having a flow passageway therethrough, a movable valve element in said valve body for controlling fuel flow through said flow passageway in which said flow passageway is open to permit fuel flow therethrough and a closed position in which said valve element at least partially blocks fuel flow through said flow passageway and means for urging said valve element toward the closed position, said valve element being movable toward the open position in response to predetermined engine operating conditions to permit fuel to flow therethrough and through said supply conduit means to said nozzle means to tailor the fuel flow to the engine.

30. A combination as defined in claim 29 wherein said means for urging includes resilient means and said means defining a fuel flow passage includes an orifice in said valve element.

31. In a fuel injection system for supplying fuel to an engine wherein the engine has a supercharger, the combination of:

- nozzle means for injecting fuel into the engine, said nozzle means being of sufficient size to permit it to supply the maximum fuel flow rate required by the engine for supercharged operation;
- supply conduit means for supplying fuel to the nozzle means at said maximum flow rate;
- a fuel pump for pumping fuel through said supply conduit means and the nozzle means to the engine, said fuel pump being driven by the engine so that the pressure of the fuel pump thereby increases with engine speed;
- a metering valve for controlling the amount of fuel pumped through said supply conduit means to said nozzle means;
- valve means in said supply conduit means for providing additional control of the fuel flow to the nozzle means;
- said valve means including a valve body having a flow passageway therethrough of sufficient size to supply fuel at said maximum fuel flow rate, a valve ele-

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ment movably mounted in said flow passageway for controlling fuel flow therethrough, and a valve seat, said valve element being movable in said flow passageway between a closed position in which said valve element engages said valve seat and an open position in which said valve element is spaced at least in part from said valve seat to permit flow through said flow passageway, said valve means also including biasing means for urging said valve element toward the closed position; and

said valve element having an aperture therethrough to permit continuous supply of fuel to said nozzle means when said valve element is in said closed position thereof, said aperture being sized to provide sufficient fuel for a first range of engine operation which amount of fuel is less than said maximum fuel flow rate, said valve element being openable in response to predetermined pressure conditions in said supply conduit means to permit supply of said maximum fuel flow rate through said flow passageway.

32. A combination as defined in claim 31 wherein said valve means is located downstream of the fuel pump and upstream of said metering valve, the combination also including means defining an acceleration chamber, said acceleration chamber being in communication with a location in said supply conduit means intermediate said valve means and said metering valve whereby fuel can be supplied to said chamber from said supply conduit means and said chamber can supply fuel to said supply conduit means depending upon the differential pressure between said chamber and said location.

33. In a fuel injection system for supplying fuel to an engine, the combination of:

supply conduit means for supplying fuel to the engine; a fuel pump for pumping fuel through said supply conduit means to the engine;

a metering valve for controlling the amount of fuel pumped through said supply conduit means to said nozzle means;

an acceleration chamber for containing a compressible fluid; and

interconnecting conduit means for providing a fluid flow path between a location in said supply conduit means upstream of said metering valve and downstream of said pump to permit the supply of fuel to said acceleration chamber when the fuel pressure at said location of said conduit means is relatively high, the supply of fuel to said acceleration chamber compressing said compressible fluid to thereby create a secondary fuel source under pressure whereby opening of the metering valve creates a relatively low pressure condition at said location in said supply conduit means to thereby permit the secondary fuel source to supply fuel to said supply conduit means.

34. A combination as defined in claim 33 including means in said interconnecting conduit means for restricting said flow passageway to thereby provide some control of the fuel flow therethrough.

35. A combination as defined in claim 33 including valve means in said supply conduit means intermediate said location in said pump, said valve means including fixed area orifice means to permit fuel to be supplied continuously therethrough and variable area passage means for providing additional fuel flow through said valve means in response to predetermined engine operating conditions.

36. A fuel injection system for supplying fuel to an engine, said fuel injection system comprising:

nozzle means for injecting fuel into the engine; supply conduit means for supplying fuel to the nozzle means;

a fuel pump for pumping fuel through said supply conduit means to the nozzle means;

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a metering valve for controlling the amount of fuel pumped through said supply conduit means to said nozzle means; said metering valve having a first position in which a first amount of fuel can flow therethrough to said nozzle means and a second position in which a substantially lesser amount of fuel can flow through the metering valve to said nozzle means;

primary bypass passage means for bypassing some of the fuel pumped by said fuel pump;

adjustable means in said primary bypass passage means for varying the rate of fuel flow therethrough;

secondary bypass passage means for bypassing some of the fuel pumped by said fuel pump; and

valve means for automatically permitting a greater quantity of fuel to be bypassed through the secondary bypass when the metering valve is in the second position than when the metering valve is in the first position.

37. A fuel injection system as defined in claim 36 wherein said adjustable means includes at least first and second fluid passages of different cross sectional areas and means for selectively causing the fuel in the primary bypass passage means to flow through said first and second fluid passages, respectively, to thereby vary the flow rate through the primary bypass passage means.

38. A fuel injection system as defined in claim 36 including a valve member in said secondary bypass passage means and means for biasing said valve member to a closed position whereby said secondary bypass passage means remains closed until sufficient fuel pressure is present to open said valve member against the force of said biasing means.

39. A combination as defined to claim 27 wherein a supercharger is provided to supply air to the engine and said valve means is responsive to said predetermined pressure condition to open at approximately the instant that there is some pressure increase in the manifold as a result of supercharger operation.

40. A combination defined in claim 29 wherein said valve means is positioned in said supply conduit means intermediate the metering valve and the fuel pump.

41. A fuel injection system for supplying fuel to an engine comprising:

a nozzle means for injecting fuel into the engine; supply conduit means for supplying fuel to the nozzle means;

a fuel pump for pumping fuel through said supply conduit means and the nozzle means to the engine;

bypass means for bypassing some of the fuel pumped by said pump;

a metering valve for controlling the amount of fuel pumped through said supply conduit means to said nozzle means, said metering valve being movable between a first position in which substantial quantity of fuel can pass therethrough to the engine and a second position in which a substantially lesser quantity of fuel can pass therethrough to the engine; means for directing more fuel through said bypass means when the metering valve is in said second position than when said metering valve is in said first position;

valve means in said supply conduit means for providing additional control over the fuel flow to said nozzle means by permitting greater quantities of fuel to flow therethrough in response to an increase in the pressure of the fuel supplied by said pump, at least some of the fuel passing through the valve means also passing through the metering valve; and means defining a fuel flow passage for supplying fuel from the pump to said nozzle means independently of said valve means.

42. A fuel injection system as defined in claim 41 wherein said bypass means includes a secondary bypass, said fuel injection system also including a primary by-

pass having a plurality of individual bypass passages therein, each of which has a maximum flow rate and means for selectively allowing fuel to flow through one of said passages while blocking fuel flow from said conduit means through the other of said passages whereby the amount of fuel returning through said primary bypass can be rapidly changed.

43. A fuel injection system as defined in claim 41 including highspeed cut-off valve means responsive to the engine exceeding approximately the speed at which horsepower is maximum for causing at least some of the excess fuel to return through said feedback conduit means at a rate which increases with respect to pump delivery rate.

44. A combination as defined in claim 3 including economizer valve means in said conduit means responsive to fuel pressure in said conduit means for providing additional control over the fuel flowing through said conduit means, at least some of the fuel flowing through said economizer valve means also flowing through said metering valve means.

45. A combination as defined in claim 10 including valve means in said conduit means responsive to a predetermined pressure condition in said conduit means for opening to permit said fuel pump to supply fuel to said nozzle through said supply conduit means and means defining a fuel flow passage for supplying fuel from the fuel pump to said inlet manifold independently of said valve means and said predetermined pressure condition whereby the opening of said valve means provides additional fuel to the inlet manifold to thereby tailor the fuel flow to the inlet manifold.

46. A combination as defined in claim 12 including pressure responsive valve means in said conduit means downstream of said fuel pump for controlling the rate of fuel flow therethrough in response to fuel pressure in said conduit means.

47. A combination as defined in claim 33 wherein said acceleration chamber is a closed and substantially fixed volume chamber.

48. A fuel injection system for supplying fuel to an engine comprising:

supply conduit means for supplying fuel to the engine;
a fuel pump for pumping fuel through said supply conduit means to the engine;

a metering valve for controlling the amount of fuel pumped through said supply conduit means to the engine;

primary bypass passage means for bypassing some of the fuel pumped by said fuel pump;

adjustable means in said primary bypass passage means for varying the rate of fuel flow therethrough;

secondary bypass passage means for bypassing some of the fuel pumped by said fuel pump; and

valve means for controlling the amount of fuel bypassed through said secondary bypass passage means, said valve means including a valve housing for receiving at least some of the fuel pumped by said fuel pump and a movable valve element in said housing, said valve element having a passageway therein movable with said valve element to selectively provide communication between the fuel pumped to said housing and the secondary bypass

passage means downstream of said valve element whereby said valve element controls fuel flow through said secondary bypass passage means.

49. A fuel injection system as defined in claim 48 wherein said valve element is rotatable, said metering valve has a first position in which a first amount of fuel can flow therethrough to the engine and a second position in which a substantially lesser amount of fuel can flow through the metering valve to the engine, and said adjustable means includes at least first and second fluid passages of different cross sectional areas and means for selectively causing the fuel in the primary bypass passage means to flow through said first and second fluid passages, respectively, to thereby vary the flow rate through the primary bypass passage means.

50. A fuel injection system for supplying fuel to an engine comprising:

supply conduit means for supplying fuel to the engine;
a fuel pump for pumping fuel through said supply conduit means to the engine;

a metering valve for controlling the amount of fuel pumped through said supply conduit means to the engine, said metering valve having a full open position in which maximum fuel flow therethrough to the engine may occur and a second position in which a substantially lesser amount of fuel can flow through the metering valve to the engine;

secondary bypass passage means for bypassing some of the fuel pumped by said fuel pump; and

valve means for controlling the amount of fuel bypassed through said secondary bypass passage means, said valve means including a valve housing for receiving at least some of the fuel pumped by said fuel pump and a movable valve element in said housing, said valve element having a passageway therein movable with said valve element to selectively provide communication between the fuel pumped to said housing and the secondary bypass passage means downstream of said valve element whereby said valve element controls fuel flow through said secondary bypass passage means.

51. A fuel injection system as defined in claim 50 wherein said valve element is rotatable relative to said housing, said fuel injection system also including a valve member in said secondary bypass passage means and means for biasing said valve member to a closed position whereby said secondary bypass passage means remains closed until sufficient fuel pressure is present to open said valve member against the force of said biasing means.

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