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Hoppe et al.

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(54) **METHOD OF CONTROLLING A FUEL INJECTOR**

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F02M 69/04 (2006.01)
F02M 35/10 (2006.01)

(52) **U.S. Cl.**

CPC ***F02M 69/044*** (2013.01); ***F02D 9/105*** (2013.01); *F02D 9/1065* (2013.01); *F02D 2200/0404* (2013.01); *F02M 35/10216* (2013.01)

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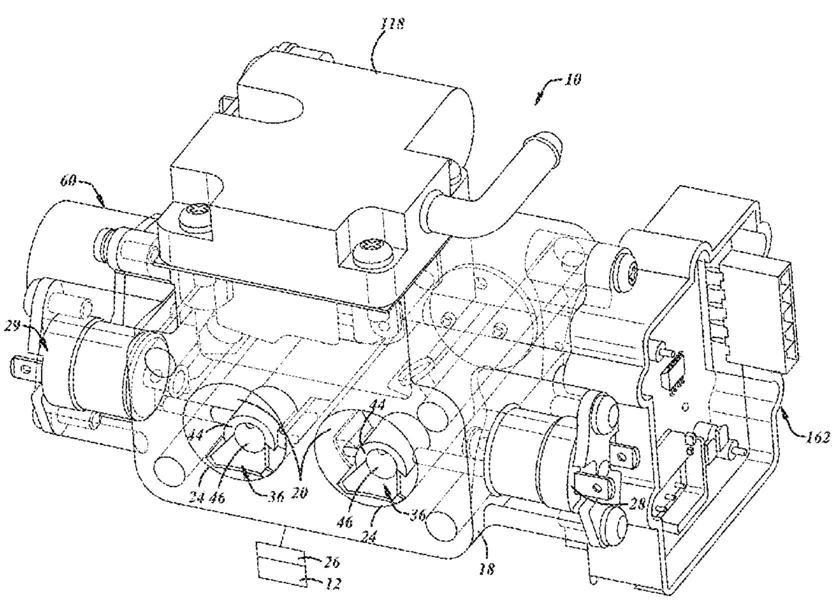
(57) **ABSTRACT**

In at least some implementations, a charge forming device includes a body that has a throttle bore, a throttle valve associated with the throttle bore, a coupler and an actuator. The throttle has a valve head received within and movable relative to the throttle bore, and a valve shaft to which the valve head is coupled. The coupler is connected to the valve shaft and carries or includes a sensor element. And the actuator has a drive shaft coupled to the coupler so that rotation of the drive shaft is transmitted to the coupler and the valve shaft.

18 Claims, 8 Drawing Sheets



Related U.S. Application Data

division of application No. 17/606,527, filed as application No. PCT/US2020/030368 on Apr. 29, 2020, now Pat. No. 11,655,788.

(60) Provisional application No. 62/842,795, filed on May 3, 2019.

(58) **Field of Classification Search**
USPC 123/336
See application file for complete search history.

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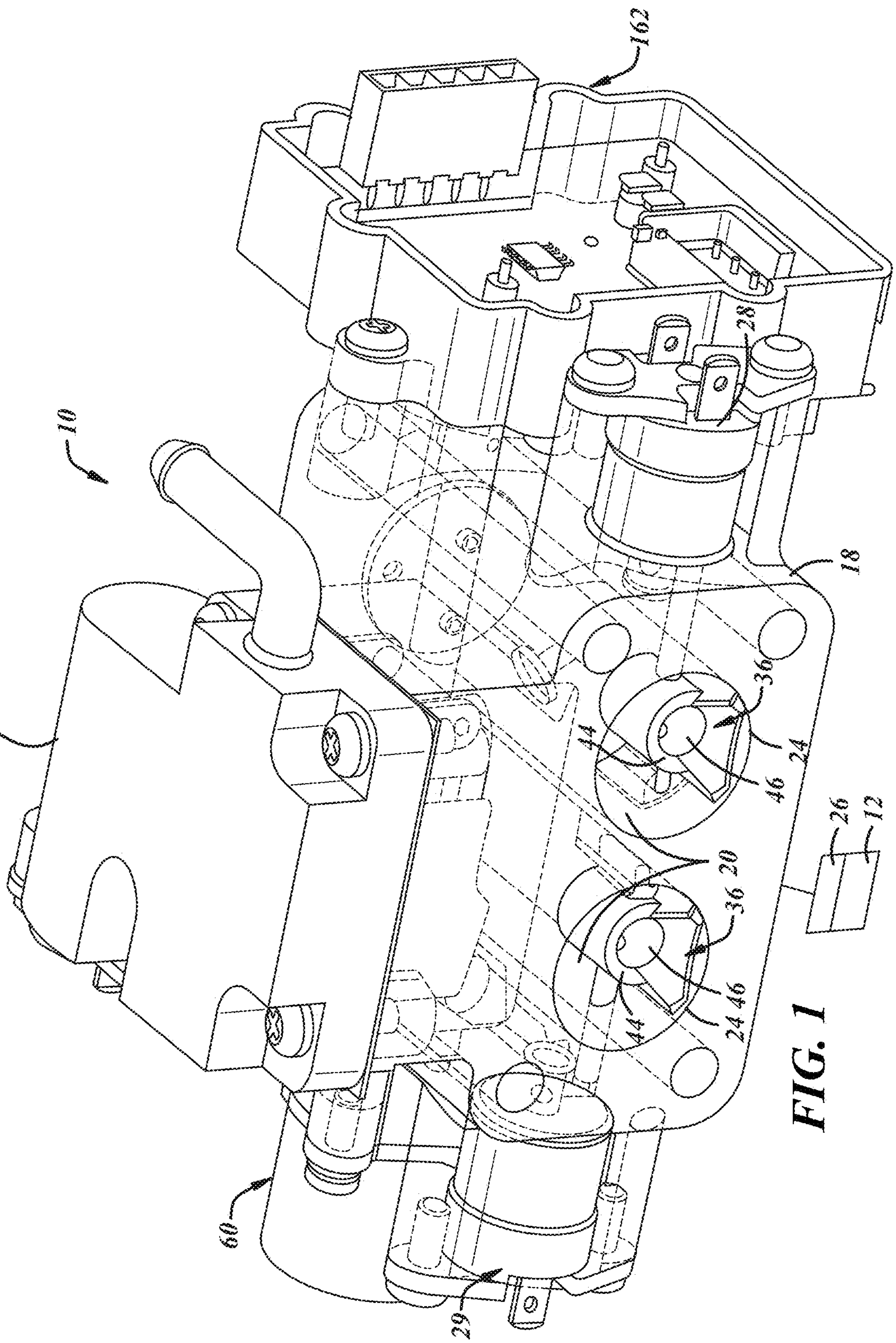

FIG. 1

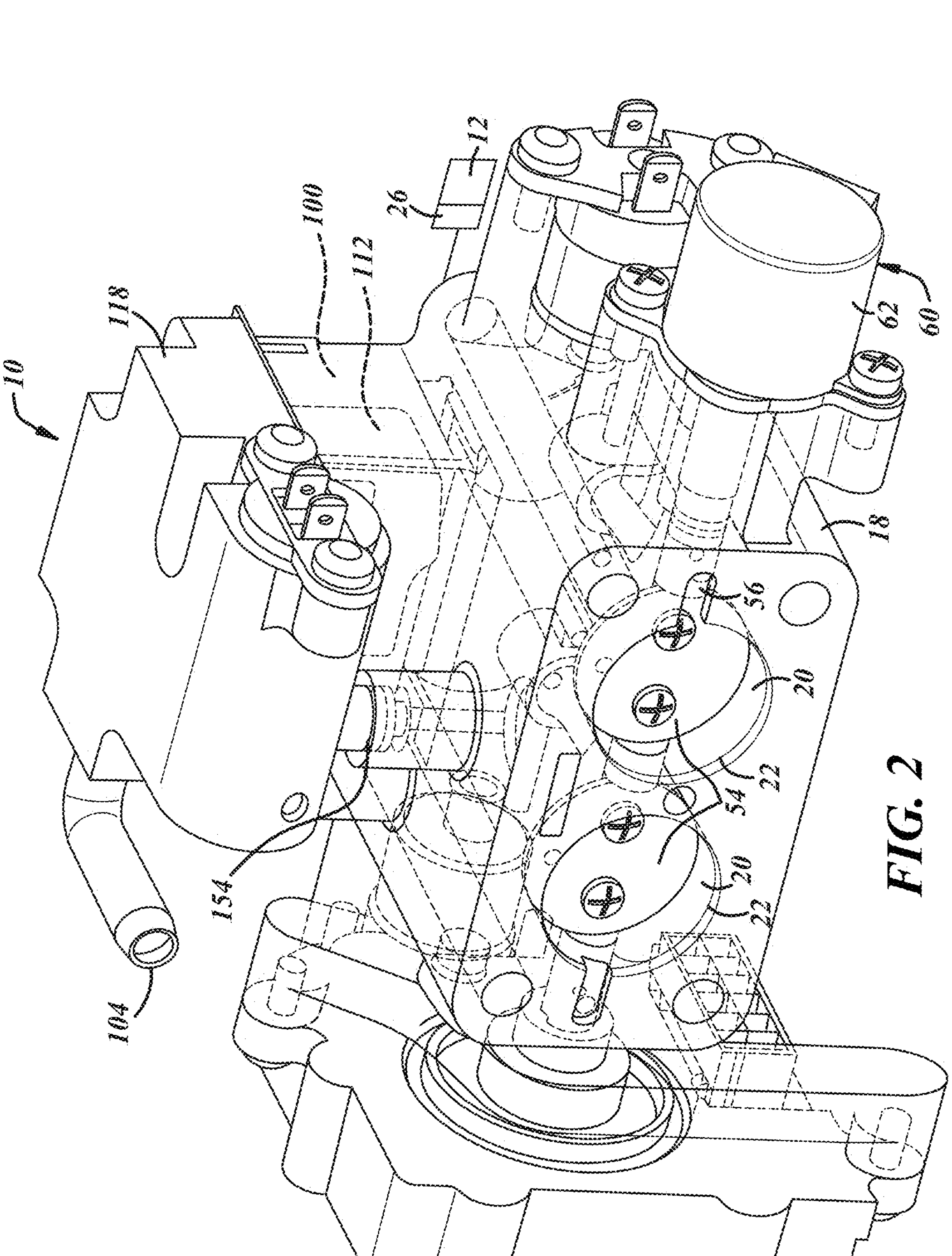

FIG. 2

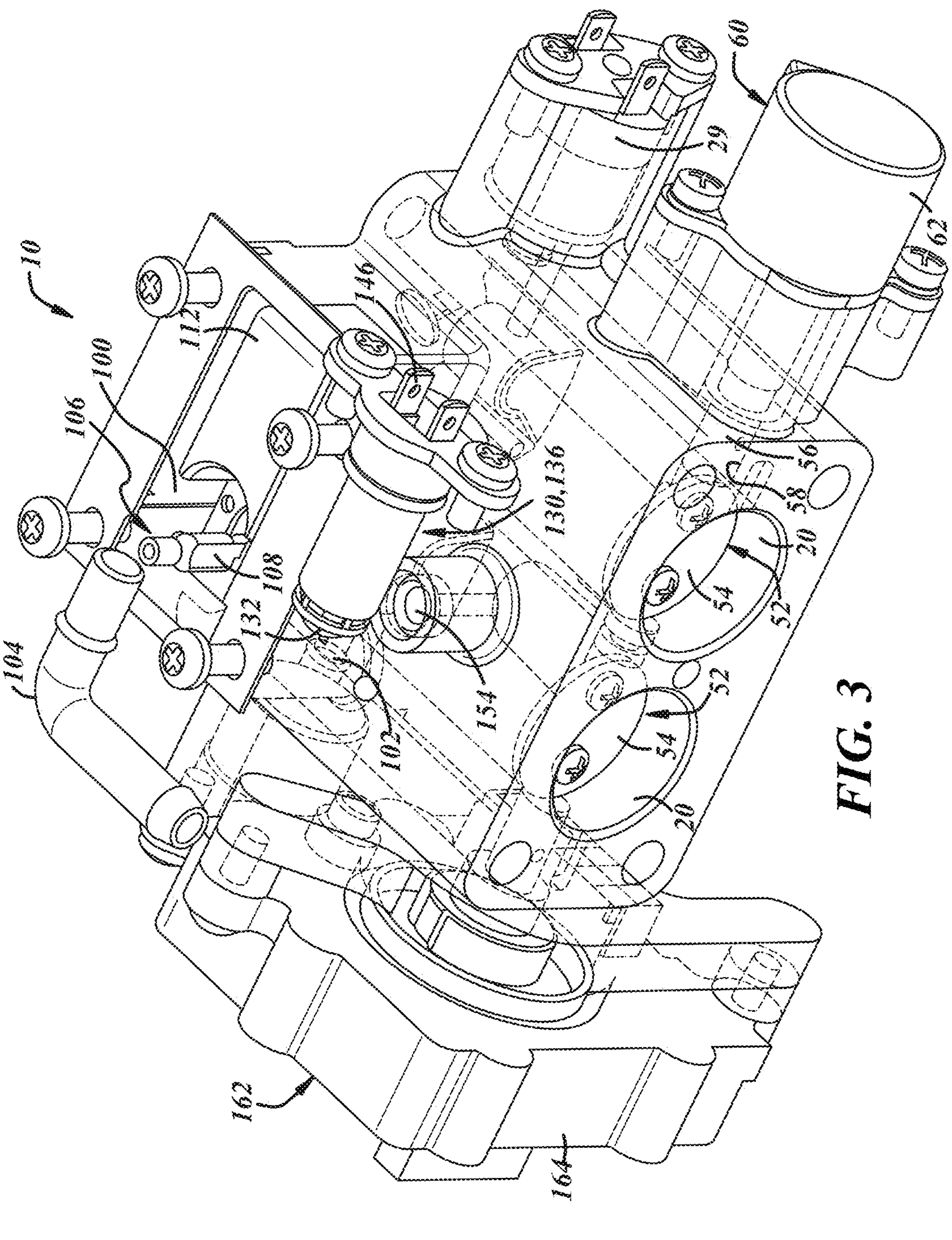
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FIG. 3

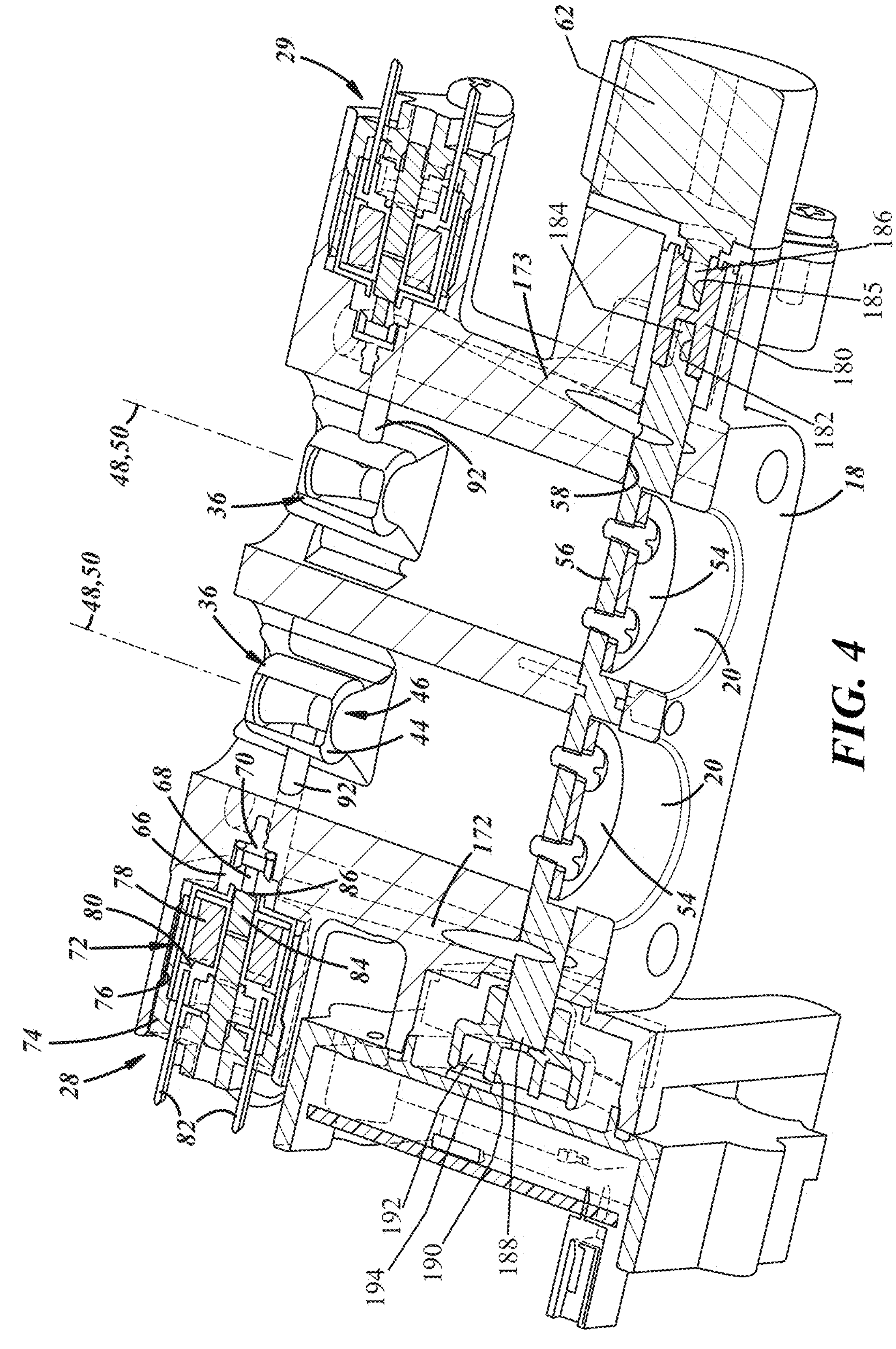
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FIG. 4

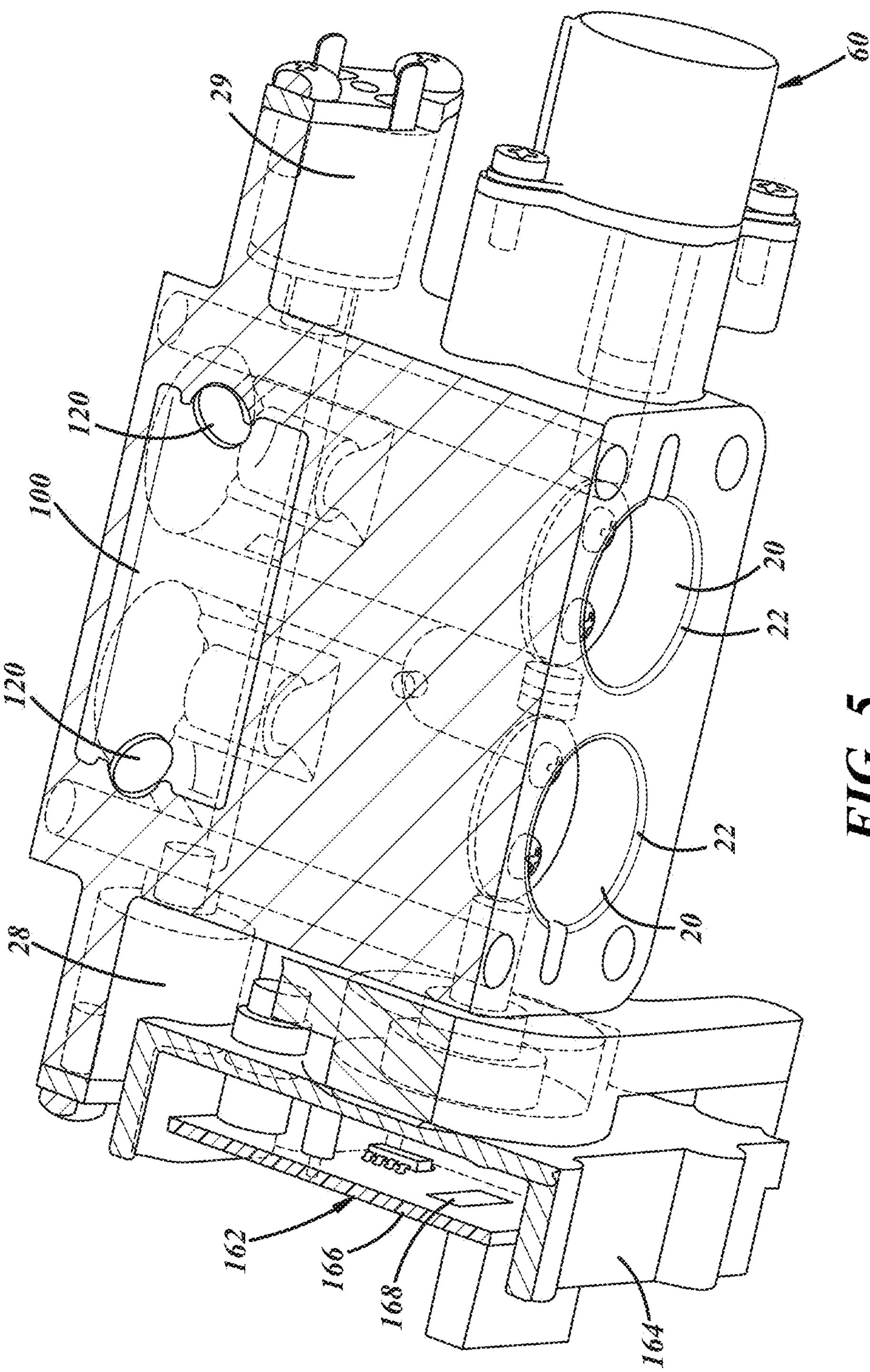

FIG. 5

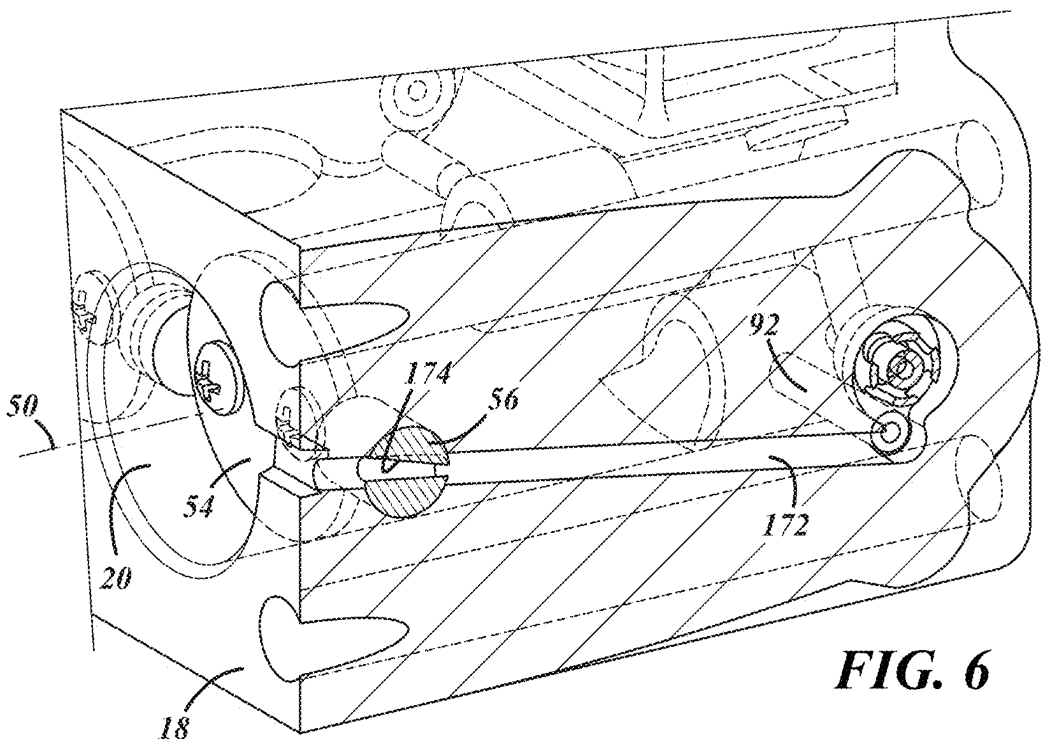

FIG. 6

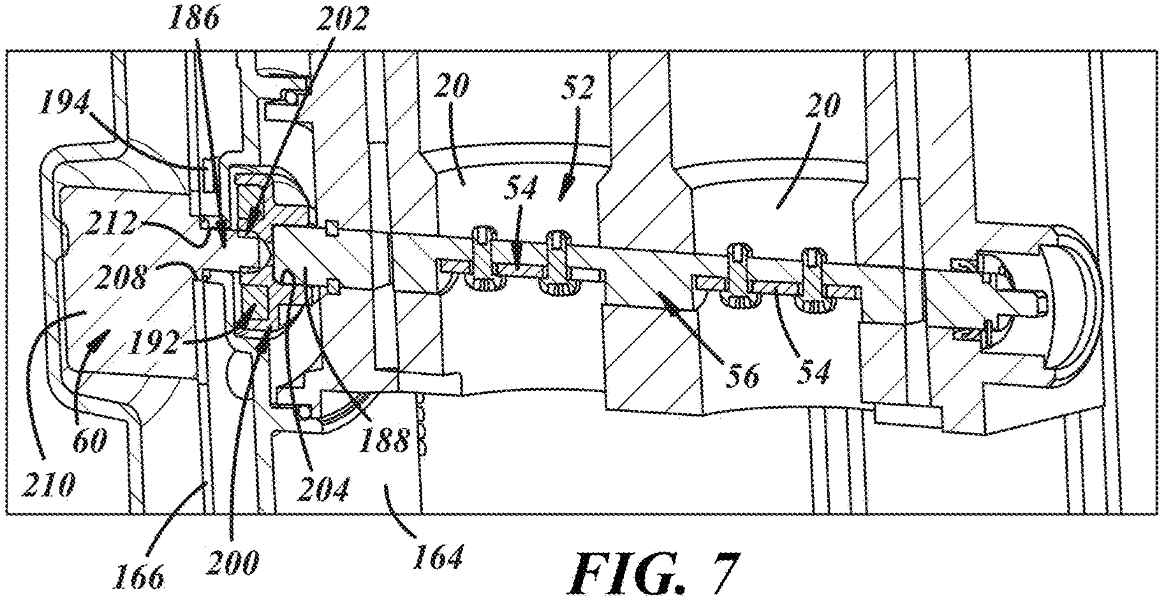

FIG. 7

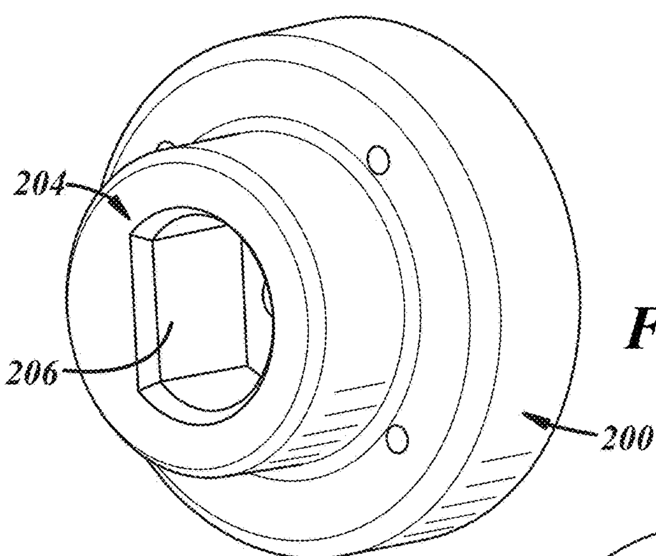

FIG. 8

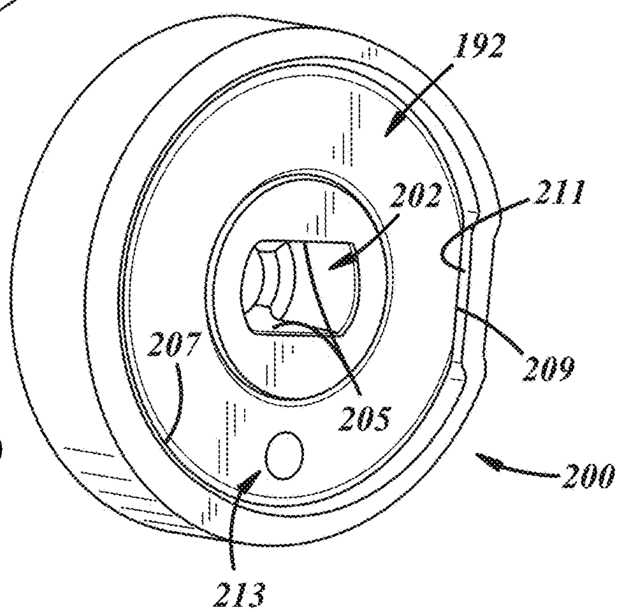

FIG. 9

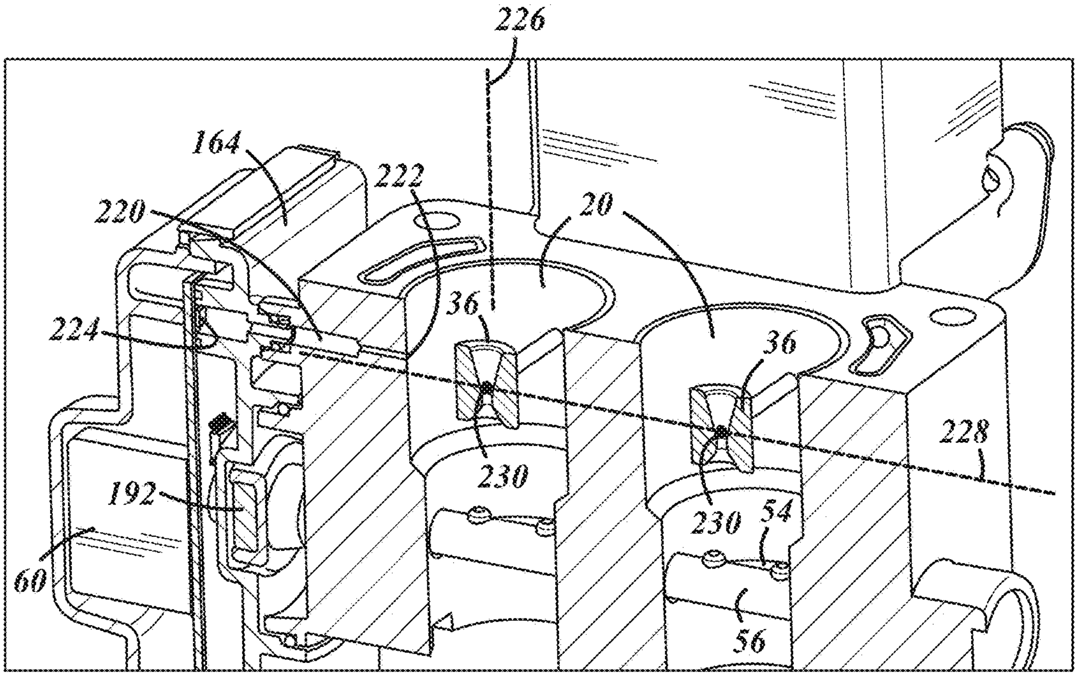
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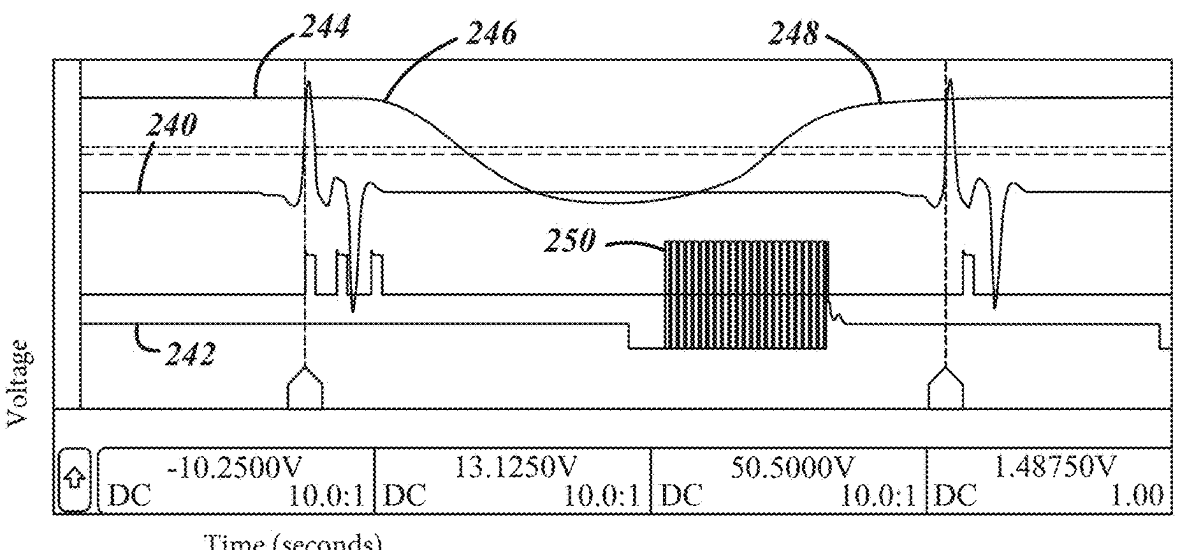
FIG. 10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250
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Voltage
-10.2500V
DC
10.0:1
13.1250V
DC
10.0:1
50.5000V
DC
10.0:1
1.48750V
DC
1.00
Time (seconds)

FIG. 11

METHOD OF CONTROLLING A FUEL INJECTOR

REFERENCE TO CO-PENDING APPLICATION

This application is a divisional of U.S. patent application Ser. No. 18/132,641 filed on Apr. 10, 2023, which is a divisional of Ser. No. 17/606,527 filed Oct. 26, 2021 now U.S. Pat. No. 11,655,788 issued on May 23, 2023, which is a national phase of PCT/US2020/030368, filed Apr. 29, 2020 and claims the benefit of U.S. Provisional Application Ser. No. 62/842,795 filed on May 3, 2019. The entire contents of these priority applications are incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates generally to a throttle valve associated with a rotary position sensor.

BACKGROUND

Fuel systems including electronic fuel injectors typically provide fuel at relatively high pressure to and from the fuel injectors. The injection pressure may be constant so that the duration over which the injector is open determines the amount of fuel discharged from the injector. Such systems may be relatively complex and require multiple sensors some of which may be relatively costly, like oxygen sensors in an exhaust gas, and high pressure pumps to provide fuel to the injectors at the high pressure. Such fuel systems are too expensive and complex for a wide range of engine applications.

SUMMARY

In at least some implementations, a charge forming device includes a body that has a throttle bore, a throttle valve associated with the throttle bore, a coupler and an actuator. The throttle has a valve head received within and movable relative to the throttle bore, and a valve shaft to which the valve head is coupled. The coupler is connected to the valve shaft and carries or includes a sensor element. And the actuator has a drive shaft coupled to the coupler so that rotation of the drive shaft is transmitted to the coupler and the valve shaft.

In at least some implementations, the coupler includes a first drive feature engaged with the drive shaft and a second drive feature engaged with the valve shaft. In at least some implementations, the coupler includes an anti-rotation feature and the sensor element includes an anti-rotation feature that is engaged with the anti-rotation feature of the coupler to prevent rotation of the sensor element relative to the coupler. The anti-rotation features of both the coupler and the sensor element may be defined by at least one flat surface. The coupler may include a cavity in which the sensor element is at least partially received, and the anti-rotation feature of the coupler may be defined by a surface that defines the cavity.

In at least some implementations, the coupler is flexible and may twist to permit movement of drive shaft relative to the throttle valve shaft when sufficient force is applied to the coupler. And the coupler is resilient so that the coupler untwists when the force causing the twisting is decreased sufficiently to permit untwisting of the coupler.

In at least some implementations, the device includes a circuit board and a sensor on the circuit board that is responsive to movement of the sensor element, and the coupler is mounted to an end of the throttle valve shaft that is closest to the circuit board. The throttle valve shaft or the drive shaft may extend through a void in the circuit board. The actuator may be located adjacent to a first side of the circuit board and the coupler may be located adjacent to a second side of the circuit board that is opposite to the first side.

In at least some implementations, a charge forming device includes a fuel injector having an electrically actuated valve and an outlet port, and fuel flows through the outlet port when the valve is open, and a pressure sensor arranged so that the pressure sensor is communicated with the pressure in the area of the outlet port.

In at least some implementations, the device also includes a controller communicated with the pressure sensor, and wherein the controller controls opening of the valve at least in part as a function of the pressure at the pressure sensor.

In at least some implementations, the device also includes a body having a throttle bore, and wherein the outlet port opens into the throttle bore and the body includes a passage that opens into the throttle bore in the area of the outlet port. The passage is communicated with the pressure sensor so that an output of the pressure sensor is indicative of the pressure within the passage. In at least some implementations, the throttle bore has an axis and a plane perpendicular to the axis and intersecting the outlet port is within one inch of an end of the passage that is open to the throttle bore.

In at least some implementations, the device also comprises a body having a throttle bore with a venturi located within the throttle bore, and wherein the outlet port opens into the venturi, and wherein the pressure sensor is responsive to the pressure within the area of the venturi. The body may include a passage that has a first end that is open to the throttle bore within one inch of the venturi and wherein the passage is communicated with the pressure sensor.

In at least some implementations, a method of controlling fuel injection events includes sensing the pressure at or near a fuel injector outlet and opening a valve of the fuel injector when the pressure at or near the fuel injector is a negative relative pressure. In at least some implementations, the method also includes determining the portion of a negative pressure signal in which to open the valve. In at least some implementations, the method also comprises comparing the sensed pressure to a threshold and opening the valve when the pressure exceeds the threshold. In at least some implementations, opening of the valve is controlled as a function of the magnitude of the pressure at or near the outlet of the fuel injector. And in at least some implementations, the pressure is continuously measured or sensed, or sampled at fixed rate.

BRIEF DESCRIPTION OF THE DRAWINGS

The following detailed description of certain embodiments and best mode will be set forth with reference to the accompanying drawings, in which:

FIG. **1** is a perspective view of a throttle body assembly having multiple bores from which a fuel and air mixture may be delivered to an engine, a main body of the throttle body assembly is shown transparent to show certain internal components and features;

FIG. **2** is another perspective view of the throttle body assembly;

FIG. **3** is another perspective view of the throttle body assembly with a vapor separator cover removed;

FIG. **4** is a perspective sectional view of a throttle body assembly;

FIG. **5** is a perspective sectional view of a throttle body assembly;

FIG. **6** is an enlarged, fragmentary perspective view of a portion of a throttle body assembly showing an air induction path and valve;

FIG. **7** is a fragmentary sectional view of a throttle body assembly including an actuator driven throttle valve and a position sensing arrangement;

FIG. **8** is a perspective view of a coupler;

FIG. **9** is another perspective view of the coupler;

FIG. **10** is a fragmentary sectional view of a throttle body assembly having two throttle bores; and

FIG. **11** is a graph showing waveforms associated with ignition events, pressure near an injector carried by the throttle body and injector events.

DETAILED DESCRIPTION

Referring in more detail to the drawings, FIGS. **1-3** illustrate a charge forming device **10** that provides a combustible fuel and air mixture to an internal combustion engine **12** (shown schematically in FIG. **1**) to support operation of the engine. The charge forming device **10** may be utilized on a two or four-stroke internal combustion engine, and in at least some implementations, includes a throttle body assembly **10** from which air and fuel are discharged for delivery to the engine.

The assembly **10** includes a housing having a throttle body **18** that has more than one throttle bore **20** (shown as two separate bores extending through the body parallel to each other) each having an inlet **22** (FIG. **2**) through which air is received into the throttle bore **20** and an outlet **24** (FIG. **1**) connected or otherwise communicated with the engine (e.g. an intake manifold **26** thereof). The inlets may receive air from an air filter (not shown), if desired, and that air may be mixed with fuel provided from separate fuel metering valves **28**, **29** carried by or communicated with the throttle body **18**. The intake manifold **26** generally communicates with a combustion chamber or piston cylinder of the engine during sequentially timed periods of a piston cycle. For a four-stroke engine application, as illustrated, the fluid may flow through an intake valve and directly into the piston cylinder. Alternatively, for a two-stroke engine application, typically air flows through the crankcase (not shown) before entering the combustion chamber portion of the piston cylinder through a port in the cylinder wall which is opened intermittently by the reciprocating engine piston.

The throttle bores **20** may have any desired shape including (but not limited to) a constant diameter cylinder or a venturi shape wherein the inlet leads to a tapered converging portion that leads to a reduced diameter throat that in turn leads to a tapered diverging portion that leads to the outlet **24**. The converging portion may increase the velocity of air flowing into the throat and create or increase a pressure drop in the area of the throat. In at least some implementations, a secondary venturi, sometimes called a boost venturi **36** may be located within one or more of the throttle bores **20** whether the throttle bore **20** has a venturi shape or not. The boost venturis may be the same, if desired, and only one will be described further. The boost venturi **36** may have any desired shape, and as shown in FIGS. **1** and **4**, has a converging inlet portion that leads to a reduced diameter intermediate throat that leads to a diverging outlet. The boost venturi **36** may be coupled the to throttle body **18** within the throttle bore **20**, and in some implementations, the throttle body may be cast from a suitable metal and the boost venturi **36** may be formed as part of the throttle body, in other words, from the same piece of material cast as a feature of the throttle body when the remainder of the throttle body is formed. The boost venturi **36** may also be an insert coupled in any suitable manner to the throttle body **18** after the throttle body is formed. In the example shown, the boost venturi **36** includes a wall **44** that defines an inner passage **46** that is open at both its inlet and outlet to the throttle bore **20**. A portion of the air that flows through the throttle body **18** flows into and through the boost venturi **36** which increases the velocity of that air and decreases the pressure thereof. The boost venturi **36** may have a center axis **48** (FIG. **4**) that may be generally parallel to a center axis **50** (FIG. **4**) of the throttle bore **20** and radially offset therefrom, or the boost venturi **36** may be oriented in any other suitable way.

Referring to FIG. **1**, the air flow rate through the throttle bore **20** and into the engine is controlled at least in part by one or more throttle valves **52**. In at least some implementations, the throttle valve **52** includes multiple heads **54** received one in each bore **20**, each head may include a flat plate coupled to a rotating throttle valve shaft **56**. The shaft **56** extends through a shaft bore **58** formed in the throttle body **18** that intersects and may be generally perpendicular to the throttle bores **20**. The throttle valve **52** may be driven or moved by an actuator **60** between an idle position wherein the heads **54** substantially block air flow through the throttle bores **20** and a fully or wide-open position wherein the heads **54** provide the least restriction to air flow through the throttle bores **20**. In one example, the actuator **60** may be an electrically driven motor **62** coupled to the throttle valve shaft **56** to rotate the shaft and thus rotate the valve heads **54** within the throttle bores **20**. In another example, the actuator **60** may include a mechanical linkage, such as a lever attached to a throttle valve shaft **56** to which a Bowden wire may be connected to manually rotate the shaft **56** as desired and as is known in the art. In this way, multiple valve heads may be carried on a single shaft and rotated in unison within different throttle bores. A single actuator may drive the throttle valve shaft, and a single throttle position sensor may be used to determine the rotary position of the throttle valve (e.g. the valve heads **54** within the throttle bores **20**).

The fuel metering valves **28** may be the same for each bore **20** and so only one is described further. The fuel metering valve **28** may have an inlet **66** to which fuel is delivered, a valve element **68** (e.g. a valve head) that controls fuel flow rate and an outlet **70** downstream of the valve element **68**. To control actuation and movement of the valve element **68**, the fuel metering valve **28** may include or be associated with an electrically driven actuator **72** such as (but not limited to) a solenoid. Among other things, the solenoid **72** may include an outer casing **74** received within a cavity **76** in the throttle body **18**, a coil **78** wrapped around a bobbin **80** received within the casing **74**, an electrical connector **82** arranged to be coupled to a power source to selectively energize the coil **78**, and an armature **84** slidably received within the bobbin **80** for reciprocation between advanced and retracted positions. The valve element **68** may be carried by or otherwise moved by the armature **84** relative to a valve seat **86** that may be defined within one or both of the solenoid **72** and the throttle body **18**. When the armature **84** is in its retracted position, the valve element **68** is removed or spaced from the valve seat **86** and fuel may flow through the valve seat. When the armature **84** is in its extended position, the valve element **68** may be closed against or bears on the valve seat **86** to inhibit or prevent fuel flow through the valve seat. In the example shown, the valve seat **86** is defined within the cavity **76** of the throttle body **18** and may be defined by a feature of the throttle body or by a component inserted into and carried by the throttle body or the solenoid casing **74**. The solenoid **72** may be constructed as set forth in U.S. patent application Ser. No. 14/896,764. The inlet **68** may be centrally or generally coaxially located with the valve seat **86**, and the outlet **70** may be radially outwardly spaced from the inlet and generally radially outwardly oriented. Of course, other metering valves, including but not limited to different solenoid valves or commercially available fuel injectors, may be used instead if desired in a particular application.

Fuel that flows through the valve seat **86** (e.g. when the valve element **68** is moved from the valve seat by retraction of the armature **84**), flows to the metering valve outlet **70** for delivery into the throttle bore **20**. In at least some implementations, fuel that flows through the outlet **70** is directed into the boost venturi **36**, when a boost venturi **36** is included in the throttle bore **20**. In implementations where the boost venturi **36** is spaced from the outlet **70**, an outlet tube **92** (FIG. **4**) may extend from a passage or port defining at least part of the outlet **70** and through an opening in the boost venturi wall **44** to communicate with the boost venturi passage **46**. The tube **92** may extend into and communicate with the throat **40** of the boost venturi **36** wherein a negative or subatmospheric pressure signal may be of greatest magnitude, and the velocity of air flowing through the boost venturi **36** may be the greatest. Of course, the tube **92** may open into a different area of the boost venturi **36** as desired. Further, the tube **92** may extend through the wall **44** so that an end of the tube projects into the boost venturi passage **46**, or the tube may extend through the boost venturi passage so that an end of the tube intersects the opposite wall of the boost venturi and may include holes, slots or other features through which fuel may flow into the boost venturi passage **46**, or the end of the tube may be within the opening **94** and recessed or spaced from the passage (i.e. not protruding into the passage).

Further, as shown in FIGS. **4** and **6**, air induction passages **172**, **173** may be used with each or any one of multiple metering valves **28** when more than one metering valve is used. The air induction passages **172**, **173** may extend from a portion of the throttle bores **20** upstream of the fuel outlet of the metering valve with which it is associated and may communicate with the fuel passage leading to the fuel outlet of the metering valve. In the example shown, the air induction passages **172**, **173** lead from an inlet end **22** of the throttle body **18** and to the fuel outlet passages.

In the example where a fuel tube **92** extends into a boost venturi **36**, the induction passages **172**, **173** may extend into or communicate with the fuel tube (as shown in FIG. **6**) to provide air from the induction passages and fuel from the metering valves **28** into the fuel tubes **92** where it may be mixed with air flowing through the throttle bores **20** and boost venturis **36**.

A jet of other flow controller may be provided in the induction passages **172**, **173** to control the flow rate of air in the passages, if desired. In addition to or instead of a jet or other flow controller, the flow rate through the induction passages **172**, **173** may be controlled at least in part by a valve. The valve could be located anywhere along the passages **172**, **173**, including upstream of the inlet of the passages. In at least one implementation, the valve may be defined at least in part by the throttle valve shaft **56**. In this example, the induction passage **172** intersects or communicates with the throttle shaft bore so that air that flows through the induction passages flows through the throttle shaft bore before the air is discharged into the throttle bore. Separate voids, like holes **174** or slots, may be formed in the throttle valve shaft **56** (e.g. through the shaft, or into a portion of the periphery of the shaft) and aligned with the passages **172**, **173**, as shown in FIG. **6**. As the throttle valve shaft **56** rotates, the extent to which the void is aligned or registered with the induction passage changes. Thus, the effective or open flow area through the valve changes which may change the flow rate of air provided from the induction passage. If desired, in at least one position of the throttle valve, the voids may be not open at all to the induction passages such that air flow from the induction passages past the throttle valve bore does not occur or is substantially prevented. Hence, the air flow provided from the induction passages to the throttle bore may be controlled at least in part as a function of the throttle valve position.

Fuel may be provided from a fuel source to the metering valve inlet **66** and, when the valve element **68** is not closed on the valve seat **86**, fuel may flow through the valve seat and the metering valve outlet **70** and to the throttle bore **20** to be mixed with air flowing therethrough and to be delivered as a fuel and air mixture to the engine. The fuel source may provide fuel at a desired pressure to the metering valve **28**. In at least some implementations, the pressure may be ambient pressure or a slightly superatmospheric pressure up to about, for example, 6 psi above ambient pressure.

To provide fuel to the metering valve inlet **66**, the throttle body assembly **10** may include an inlet chamber **100** (FIG. **3**) into which fuel is received from a fuel supply, such as a fuel tank. The throttle body assembly **10** may include a fuel inlet **104** leading to the inlet chamber **100**. In a system wherein the fuel pressure is generally at atmospheric pressure, the fuel flow may be fed under the force of gravity to the inlet chamber **100**. In at least some implementations, as shown in FIGS. **3** and **4**, a valve assembly **106** may control the flow of fuel into the inlet chamber **100**. The valve assembly **106** may include a valve element **108** and may include or be associated with a valve seat so that a portion of the valve element **108** is selectively engageable with the valve seat to inhibit or prevent fluid flow through the valve seat, as will be described in more detail below. The valve element **108** may be coupled to an actuator **112** that moves the valve **108** relative to the valve seat, as will be set forth in more detail below. A vent port or passage **102** (FIGS. **4** and **5**) may be communicated with the inlet chamber and with the engine intake manifold or elsewhere as desired so long as the desired pressure within the inlet chamber **100** is achieved in use, which may include atmospheric pressure. The level of fuel within the inlet chamber **100** provides a head or pressure of the fuel that may flow through the metering valve **28** when the metering valve is open.

To maintain a desired level of fuel in the inlet chamber **100**, the valve **108** is moved relative to the valve seat by the actuator **112** which, in the example shown, includes or is defined by a float that is received in the inlet chamber and is responsive to the level of fuel in the inlet chamber. The float **112** may be buoyant in fuel and provide a lever pivotally coupled to the throttle body **18** or a cover **118** coupled to the body **18** on a pin and the valve **108** may be connected to the float **112** for movement as the float moves in response to changes in the fuel level within the inlet chamber **100**. When a desired maximum level of fuel is present in the inlet chamber **100**, the float **112** has been moved to a position in the inlet chamber wherein the valve **108** is engaged with and closed against the valve seat, which closes the fuel inlet **104** and prevents further fuel flow into the inlet chamber **100**. As fuel is discharged from the inlet chamber **100** (e.g. to the throttle bore **20** through the metering valve **28**), the float **112** moves in response to the lower fuel level in the inlet chamber and thereby moves the valve **108** away from the valve seat so that the fuel inlet **104** is again open. When the fuel inlet **104** is open, additional fuel flows into the inlet chamber **100** until a maximum level is reached and the fuel inlet **104** is again closed.

The inlet chamber **100** may be defined at least partially by the throttle body **18**, such as by a recess formed in the throttle body, and a cavity in the cover **118** carried by the throttle body and defining part of the housing of the throttle body assembly **10**. Outlets **120** (FIG. **5**) of the inlet chamber **100** leads to the metering valve inlet **66** of each metering valve **28**, **29**. So that fuel is available at the metering valve **28** at all times when fuel is within the inlet chamber **100**, the outlet **120** may be an open passage without any intervening valve, in at least some implementations. The outlet **120** may extend from the bottom or a lower portion of the inlet chamber so that fuel may flow under atmospheric pressure to the metering valve **28**.

In use of the throttle body assembly **10**, fuel is maintained in the inlet chamber **100** as described above and thus, in the outlet **120** and the metering valve inlet **66**. When the metering valve **28** is closed, there is no, or substantially no, fuel flow through the valve seat **86** and so there is no fuel flow to the metering valve outlet **70** or to the throttle bore **20**. To provide fuel to the engine, the metering valve **28** is opened and fuel flows into the throttle bore **20**, is mixed with air and is delivered to the engine as a fuel and air mixture. The timing and duration of the metering valve opening and closing may be controlled by a suitable microprocessor or other controller. The fuel flow (e.g. injection) timing, or when the metering valve **28** is opened during an engine cycle, can vary the pressure signal at the outlet **70** and hence the differential pressure across the metering valve **28** and the resulting fuel flow rate into the throttle bore **20**. Further, both the magnitude of the engine pressure signal and the airflow rate through the throttle valve **52** change significantly between when the engine is operating at idle and when the engine is operating at wide open throttle. In conjunction, the duration that the metering valve **28** is opened for any given fuel flow rate will affect the quantity of fuel that flows into the throttle bore **20**.

The inlet chamber **100** may also serve to separate liquid fuel from gaseous fuel vapor and air. Liquid fuel will settle into the bottom of the inlet chamber **100** and the fuel vapor and air will rise to the top of the inlet chamber where the fuel vapor and air may flow out of the inlet chamber through the vent passage **102** or vent outlet (and hence, be delivered into the intake manifold and then to an engine combustion chamber). To control the venting of gasses from the inlet chamber **100**, a vent valve **130** may be provided at the vent passage **102**. The vent valve **130** may include a valve element **132** that is moved relative to a valve seat to selectively permit fluid flow through the vent or vent passage **102**. To permit further control of the flow through the vent passage **102**, the vent valve **130** may be electrically actuated to move the valve element **132** between open and closed positions relative to the valve seat **134**.

As shown in FIGS. **4** and **5**, to control actuation and movement of a valve element **132**, the vent valve **130** may include or be associated with an electrically driven actuator such as (but not limited to) a solenoid **136**. Among other things, the solenoid **136** may include an outer casing received within a cavity in the throttle body **18** or cover **118** and retained therein by a retaining plate or body, a coil wrapped around a bobbin received within the casing, an electrical connector **146** arranged to be coupled to a power source to selectively energize the coil, an armature slidably received within the bobbin for reciprocation between advanced and retracted positions and an armature stop. The valve element **132** may be carried by or otherwise moved by the armature relative to a valve seat that may be defined within one or more of the solenoid **136**, the throttle body **18** and the cover **118**. When the armature is in its retracted position, the valve element **132** is removed or spaced from the valve seat and fuel may flow through the valve seat. When the armature **148** is in its extended position, the valve element **132** may be closed against or bears on the valve seat **134** to inhibit or prevent fuel flow through the valve seat. The solenoid **136** may be constructed as set forth in U.S. patent application Ser. No. 14/896,764. Of course, other valves, including but not limited to different solenoid valves (including but not limited to piezo type solenoid valves) or other electrically actuated valves may be used instead if desired in a particular application.

The vent passage **102** or vent outlet could be coupled to a filter or vapor canister that includes an adsorbent material, such as activated charcoal, to reduce or remove hydrocarbons from the vapor. The vent passage **102** could also or instead be coupled to an intake manifold of the engine where the vapor may be added to a combustible fuel and air mixture provided from the throttle bore **20**. In this way, vapor and air that flow through the vent valve **130** are directed to a downstream component as desired. In the implementation shown, an outlet passage **154** extends from the cover **118** downstream of the valve seat **134** and to an intake manifold of the engine (e.g. via the throttle bores **20**). While the outlet passage **154** is shown as being defined at least in part in a conduit that is routed outside of the cover **118** and throttle body **18**, the outlet passage **154** could instead be defined at least in part by one or more bores or voids formed in the throttle body and/or cover, and or by a combination of internal voids/passages and external conduit(s).

In at least some implementations, the cover **118** defines part of the inlet chamber **100** and the vent passage **102** extends at least partially within the cover and communicates at a first end with the inlet chamber **100** and at a second end with an outlet from the throttle body (e.g. the cover). The vent valve **130** and valve seat **132** are disposed between the first and second ends of the vent passage **102** so that the vent valve controls the flow through the vent passage. In the implementation shown, the vent passage **102** is entirely within the cover **118**, and the vent valve **130** is carried by the cover, e.g. within the cavity formed in the cover.

In at least some implementations, a pressure in the vent passage **102** can interfere with the fuel flow from the inlet chamber **100** to the fuel metering valve **28** and throttle bore **20**. For example, when the vent passage **102** is communicated with the intake manifold or with an air cleaner box/filter, a subatmospheric pressure may exist within the vent passage. The subatmospheric pressure, if communicated with the inlet chamber **100**, can reduce the pressure within the inlet chamber and reduce fuel flow from the inlet chamber. Accordingly, closing the vent valve **130** can inhibit or prevent communication of the subatmospheric pressure from the vent passage **102** with the inlet chamber **100**. A pressure sensor responsive to pressure in the vent passage **102** or in, for example, the intake manifold, may provide a signal that is used to control, at least in part, the actuation of the vent valve **130** as a function of the sensed pressure to improve control over the pressure in the inlet chamber. Also or instead, the vent valve **130** may be closed to permit some positive, superatmospheric pressure to exist within the inlet chamber **100** which may improve fuel flow from the inlet chamber to the throttle bore **20**. And the vent valve **130** may be opened to permit engine pressure pulses (e.g. from the intake manifold) to increase the pressure within the inlet chamber **100**. As noted above, the opening of the vent valve **130** may be timed with such pressure pulses by way of a pressure sensor or otherwise. These examples permit better control over the fuel flow from the inlet chamber **100** and thus, better control of the fuel and air mixture delivered from the throttle bore **20**. In this way, the vent valve **130** may be opened and closed as desired to vent gasses from the inlet chamber **100** and to control the pressure within the inlet chamber.

Still further, it may be desirable to close the vent passage **102** to avoid the fuel in the inlet chamber **100** from going stale over time (due to evaporation, oxidation or otherwise), such as during storage of the device with which the throttle body assembly **10** is used. In this way, the vent valve **130** may be closed when the device is not being used to reduce the likelihood or rate at which the fuel in the throttle body assembly **10** becomes stale.

Finally, when the vent valve strokes from open to closed, the armature and valve element **132** movement displace air/vapor in the vent passage **102** toward and into the inlet chamber **100** which may raise the pressure in the inlet chamber. Repeated actuations of the vent valve **130** may then provide some pressure increase, even if relatively small, that facilitates fuel flow from the inlet chamber **100** to the throttle bore **20**.

In at least some implementations, the pressure within the inlet chamber **100** may be controlled by actuation of the vent valve **130**, to be between 0.34 mmHg to 19 mmHg. In at least some implementations, the vent valve **130** may be opened and closed repeatedly with a cycle time of between 1.5 ms to 22 ms. And in at least some implementations, the vent valve **130** may be controlled at least when the throttle valve is at least 50% of the way between its idle and wide open positions (e.g. between 50% and 100% of the angular rotation from idle to wide open), for example, because the intake manifold pressure may be greater in that throttle position range and thus, more likely to interfere with the pressure in the inlet chamber.

The vent valve **130** may be actuated by a controller **162** (FIGS. **1**, **4** and **5**) that controls when electrical power is supplied to the solenoid **136**. The controller **162** may be the same controller that actuates the fuel metering valve **28** or a separate controller. Further, the controller **162** that actuates one or both of the vent valve **130** and the fuel metering valve **28** may be mounted on or otherwise carried by the throttle body assembly **10**, or the controller may be located remotely from the throttle body assembly, as desired. In the example shown, the controller **162** is carried within a sub-housing **164** that is mounted to the throttle body **18** and/or cover **118**, or otherwise carried by the housing (e.g. the body and/or cover), and which may include a printed circuit board **166** and a suitable microprocessor **168** or other controller for actuation of the metering valve **28**, vent valve **130** and/or the throttle valve (e.g. when rotated by a motor **62** as shown and described above). Further, information from one or more sensors maybe used to control, at least in part, operation of the vent valve, and the sensor(s) may be communicated with the controller that controls actuation of the vent valve.

The dual bore throttle body and fuel injection assembly may be used to provide a combustible fuel and air mixture to a multi-cylinder engine. The assembly may improve cylinder to cylinder air-fuel ratio balancing, engine starting, and overall run quality and performance compared to an assembly having a single throttle bore and a single fuel injector or point/location of fuel injection.

The system or assembly may include a low pressure fuel injection system described above with the any following additional options: a single throttle body assembly with a plurality of throttle bores; one or more vapor separators integrated into the throttle body assembly; at least one injector per throttle bore; optional boost venturi for the injector(s); a single engine control module/controller; a single throttle shaft including multiple throttle valve heads on the shaft, one in each throttle bore; a single throttle position sensor; may include a single throttle actuator which may be electronically controlled; may include two ignition coils or a double-ended ignition coil.

As shown in FIG. **7** a throttle body or other charge forming device may include one or more throttle bores **20**, and a throttle valve **52** associated with each throttle bore **20**. The throttle valves **52** may be separate or a single throttle valve shaft **56** may include multiple valve heads **54** that rotate with the shaft **56** between a first or idle position and a second or open position which may be a wide open or fully open position. In the example shown in FIG. **4**, the throttle valve shaft **56** has two valve heads **54** mounted thereon, which are shown as thin discs in a dual butterfly valve arrangement. In the first position, the valve heads **54** are generally perpendicular to fluid flow through the throttle bores **20** and provide a maximum restriction to fluid flow through the throttle bores **20** (where generally perpendicular includes perpendicular and orientations within 15 degrees of perpendicular). In the second position, the valve heads **54** are generally parallel to fluid flow through the throttle bores **20** and may provide a minimum restriction to fluid flow through the throttle bores **20** (where generally parallel includes parallel and orientations within 15 degrees of parallel).

As noted above, the throttle valve **52** may be driven or moved by the actuator **60** which may be an electrically driven motor **62** coupled to the throttle valve shaft **56** to rotate the shaft and thus rotate the valve heads **54** within the throttle bores **20**. As shown in FIG. **4**, a coupler **180** may drivingly connect the actuator **60** to the throttle valve shaft **56**. The coupler **180** may include a first recess **182** in which an end **184** of the throttle valve shaft **56** is received and a second recess **185** in which a drive shaft **186** of the actuator **60** is received. Thus, the coupler **180** in at least some implementations may be a component formed separately from the throttle valve shaft **56** and the drive shaft **186**. Suitable anti-rotation features may be provided between the coupler **180** and shafts **56** and **186** (e.g. complementary noncircular portions or surfaces) so that the throttle valve shaft **56** is rotated when the drive shaft **186** rotates. If desired, the coupler may be flexible, that is, it may twist or flex somewhat to reduce impulse forces from rapid movements (e.g. larger accelerations or decelerations) of the assembly. And the coupler **180** may be resilient so that it untwists or unflexes so that the amount of commanded rotation of the throttle valve **52** is achieved when the force causing the twisting is removed or sufficiently reduced (that is, the rotation of the actuator **60** is accurately transmitted to and results in the same amount of rotation of the throttle valve **52**).

In FIG. **4**, the coupler **180** is arranged on the end **184** of the valve shaft **56** opposite to and end **188** of the valve shaft **56** that is adjacent to the circuit board **166**. That end **188** of valve shaft **56** includes or is connected to a second coupler

190 that carries a sensor element 192 that rotates with the valve shaft 56. A sensor 194 responsive to the movement of the sensor element 192 may be mounted to the circuit board 166 or elsewhere as desired. In at least some implementations, the sensor element 192 is a magnet and the sensor 194 is responsive to movement of the magnetic field of the magnet 192 when the valve shaft 56 is rotated. This provides a non-contact sensor arrangement that enables accurate determination of the rotary or angular position of the throttle valve.

In FIG. 7, a coupler 200 interconnects the actuator 60 with the valve shaft 56 and also carries or otherwise includes the sensor element 192. This coupler 200 is mounted on the end 188 of the valve shaft 56 that is adjacent to the circuit board 166 and/or the sensor 194. As shown in FIGS. 7-9, the coupler 200 has a first drive feature 202 engaged with the drive shaft 186 of the actuator 60 for co-rotation of the coupler 200 with the drive shaft 186, and a second drive feature 204 engaged with the valve shaft 56 for co-rotation of the valve shaft 56 and coupler 200. The drive features 202, 204 may include recesses or sockets into which portions of the shafts 56, 186 extend, with non-circular portions or surfaces that prevent relative rotation of the coupler 200 relative to either shaft 56, 186, or the coupler may include projections that are received in sockets or cavities in the shafts 56, 186 or some combination of such features. In the example shown, the first drive feature 202 includes two oppositely facing flat surfaces 205 (FIG. 9) and the drive shaft end 188 is complementarily shaped, and the second drive feature 204 includes one flat surface 206 (FIG. 8), is generally D-shaped and the drive shaft 186 is complementarily shaped. Of course, other noncircular shapes and arrangements may be used as desired. The drive features 202, 204 could also be circular, if desired, and also if desired, an adhesive, set screw or other connection may be provided between the shafts 56, 186 and the coupler 200 to provide the desired co-rotation. As described above, the coupler 200 may be formed from an at least somewhat flexible material to, for example, damp impulse forces and vibrations, and is also resilient so that the desired or commanded rotation of the valve shaft 56 ultimately occurs.

The coupler 200 may include a cavity 207 in which the magnet 192 is received, and the magnet 192 and cavity 207 may have complementary anti-rotation features 209, 211 that inhibit or prevent rotation of the magnet 192 relative to the coupler 200. The anti-rotation features 209, 211 may include engaged flat surfaces (e.g. a surface that defines the cavity and an exterior surface of the magnet) or other complementary non-circular geometric features, and/or an adhesive or other connector may be used between the magnet 192 and coupler 200. Thus, the rotational position of the magnet 192 can more accurately represent the rotational position of the coupler 200 and valve shaft 56. To facilitate proper assembly and/or calibration of the sensor assembly, or for other reasons, a marking 213 or some indicia may be provided on the magnet 192 to indicate a polarity of that portion of the magnet. In the example shown, the magnet 192 can be received in the cavity 207 in two different orientations (e.g. it may be flipped over) and the indicia may help to ensure that the magnet 192 is installed in the desired orientation.

In at least some implementations, as shown in FIG. 7, one of the drive shaft 186 or valve shaft 56 extends through a void 208 in the circuit board 166. This enables the sensor element 192 to be located close to the sensor 194 (e.g. less than 8 mm away) to improve position sensing. In the example shown, a motor 210 of the actuator 60 is on a first side of the circuit board 166 and the coupler 200 is on the opposite, second side of the circuit board 166, and the drive shaft 186 extends through the void 208 in the circuit board, and an aligned void/boss 212 in the sub-housing 164 which may support and guide rotation of the drive shaft 186. The valve shaft 56 could instead extend through the void 208 in the circuit board 166, and the coupler 200 and drive shaft 186 could be located on the first side of the circuit board 166, which is the side opposite to the throttle bores 20.

In the throttle body shown in FIG. 10, a passage 220 is provided that communicates at a first end 222 with a throttle bore 20. The passage also communicates with a pressure sensor 224, which is shown as being mounted to the circuit board 166. Thus, the passage 220 in this implementation extends through the sub-housing 164 to a second end that is open to an area in which the pressure sensor 224 is located. The pressure in the throttle bore 20 in the area of the first end 222 of the passage 220 is communicated with the pressure sensor 224 which provides an output signal that corresponds to the sensed pressure.

In at least some implementations, the first end 222 of the passage 220 is arranged near an area in which fuel is injected into the throttle bore 20. The throttle bore has an axis 226. In at least some implementations, an imaginary plane 228 that is perpendicular to the axis 226, and which extends through the center of the injection port 230 through which fuel enters the throttle bore 20, intersects or is within 1-inch of the first end 222 of the passage 220. In the example shown, fuel enters the throttle bore 20 through a port 230 that is formed in a boost venturi 36 located within the throttle bore 20, as described above, with reference to, for example, FIG. 4. Of course, other arrangements may be used. Thus, the output from the pressure sensor 224 is indicative of the pressure in the area of the fuel injection port 230 and is thus indicative of the pressure that acts on fuel at the injection port 230. In at least some implementations, the timing of the fuel injection may be coordinated or chosen as a function of this sensed pressure, to control fuel flow into the throttle bore 20. Also, upon energization of the controller 162, which may occur before the engine is started, the controller 162 can interrogate or receive a signal from the pressure sensor 224 for a reference value of barometric pressure, which may be used to determine an initial ignition timing and/or fuel/air mixture calibration or for other engine control purposes.

In the graph shown in FIG. 11, a first waveform 240 relates to a voltage induced in a coil of an engine ignition system, such as by a magnet mounted to an engine flywheel. A second waveform 242 relates to a fuel metering valve or fuel injector control signal, that is, the waveform shows when a voltage is applied to open the fuel injector(s) as described above. And a third waveform 244 shows the pressure sensed by the sensor 224. A little more than one engine revolution is shown in this graph, as can be seen by the two instances in the ignition coil/sensor waveform 240 wherein a flywheel magnet induced voltage in the ignition system coil. Within this engine revolution, the pressure at sensor 224 decreased between points 246 and 248 as an engine intake valve opened and a downward-travelling piston creates a negative relative pressure in the engine intake. There generally is no negative or positive relative pressure signal when the intake valve is closed. The time when the negative pressure occurs at the injection location, which may or may not occur within the throttle body (that is the injector could be located outside of the throttle body and the pressure may be taken in the area of the injector outlet, as noted above), is the optimum time for a low-pressure injection system to open the injector and control the injection of fuel as a greater flow rate of fuel may be achieved with this negative engine pressure signal which aids fuel flow from the port **230**.

In general, the greater the magnitude of the negative relative pressure, the more fuel will flow from the injector for a given amount of time in which the injector is open and permits fuel flow. Thus, the start of the negative pressure, generally indicated at **246**, to the end of the negative pressure, generally indicated at **248**, may be the optimum time period within which to inject fuel, at least where the pressure is measured at or very near the location of injection. Of course, in at least some situations, fuel may be provided only during a portion of the negative pressure signal, and improved control of the fuel injection event may be enabled by timing the injection event to a desired portion of the negative pressure signal which does not necessarily include the maximum relative pressure.

Thus, the injection timing can be controlled as a function of the instantaneous pressure at or near the injection outlet or port. The pressure may be continuously measured or sensed, or sampled at fixed rate, as desired. Further, the injection event may be tied to one or more pressure thresholds so that a known flow rate of fuel can be achieved and the efficiency of the fuel injection events can be improved. In the example shown in FIG. **11**, a signal indicated at **250** is provided from a controller to the fuel injector (or fuel metering valve which may considered to be a fuel injector) to open a valve of the fuel injector and cause fuel to flow when the pressure signal exceeds a threshold relative pressure. Thus, until the pressure signal exceeds the threshold, the injector valve is closed and fuel is not delivered from the injector. The injection strategies described herein may improve fuel injection efficiency, in, but not limited to, situations in which a sensed or calculated crankshaft angular position may not be as accurate as desired, such as during engine acceleration or deceleration. Additionally, any changes in the pressure signal due to degradation of the engine system (pumping efficiency due to wear, air filter being plugged, etc) can be compensated for to continue to inject fuel at optimum relative negative pressure, despite the change in shape, magnitude, or timing of the relative negative pressure pulse (which calibration based on engine crankshaft angular displacement/position cannot instantaneously compensate for).

The forms of the invention herein disclosed constitute presently preferred embodiments and many other forms and embodiments are possible. It is not intended herein to mention all the possible equivalent forms or ramifications of the invention. It is understood that the terms used herein are merely descriptive, rather than limiting, and that various changes may be made without departing from the spirit or scope of the invention.

As used in this specification and claims, the terms "for example," "for instance," "e.g.," "such as," and "like," and the verbs "comprising," "having," "including," and their other verb forms, when used in conjunction with a listing of one or more components or other items, are each to be construed as open-ended, meaning that that the listing is not to be considered as excluding other, additional components or items. Other terms are to be construed using their broadest reasonable meaning unless they are used in a context that requires a different interpretation.

The invention claimed is:

1. A method of controlling fuel injection events in an internal combustion engine, the method comprising the steps of:

sensing pressure at or near an outlet of a fuel injector with a negative pressure sensor to generate a negative pressure signal; and

processing the negative pressure signal, by a controller, during each engine revolution so that when an intake valve of the internal combustion engine is open and a piston is travelling downward to create a negative relative pressure as sensed by the negative pressure sensor at or near the outlet of the fuel injector, the controller opens a fuel metering valve of the fuel injector so that the negative relative pressure aids fuel flow from the fuel metering valve.

2. The method of claim **1**, wherein the controller opens the fuel metering valve for a duration within each engine revolution and the duration is within and smaller than a portion of the engine revolution in which the negative pressure signal is at or below a threshold relative pressure.

3. The method of claim **2**, wherein the duration does not include a maximum relative pressure in the respective engine revolution.

4. The method of claim **1**, wherein the duration occurs after a maximum relative pressure in the respective engine revolution.

5. The method of claim **1**, which also comprises comparing the sensed pressure to a threshold and opening the fuel metering valve when the pressure exceeds the threshold.

6. The method of claim **1**, wherein the pressure is sampled at fixed rate.

7. The method of claim **1**, further comprising the step of processing the negative pressure signal, by the controller, during each engine revolution so that when the intake valve of the internal combustion engine is closed and, in turn, there is no negative relative pressure as sensed by the negative pressure sensor at or near the outlet of the fuel injector, the controller closes the fuel metering valve of the fuel injector.

8. The method of claim **1**, further comprising the step of receiving a signal, upon energization of the controller and before the internal combustion engine starts, from the pressure sensor to utilize as a reference value for barometric pressure in a calculation for a desired fuel/air mixture calibration.

9. The method of claim **1**, further comprising the step of receiving a signal, upon energization of the controller and before the engine starts, from the pressure sensor to utilize as a reference value for barometric pressure in a calculation for initial engine timing.

10. The method of claim **1**, wherein the fuel injector is located outside of the throttle body.

11. The method of claim **1**, further comprising controlling venting of gasses from by providing a venting system, the venting system having a vent valve including a valve element that is moved relative to a valve seat to selectively permit fluid flow through the vent valve to facilitate fuel flow to the fuel metering valve when a throttle valve is at least 50% from an idle position to a wide open position.

12. A method of controlling fuel injection of a throttle body assembly, comprising:

providing a fuel metering valve with an inlet to which fuel is delivered, a valve element that controls fuel flow rate, and an outlet downstream of the valve element;

providing an actuator with an armature slidably configured for reciprocation between extended and retracted positions, the valve element moved by the armature relative to a valve seat;

providing a sensor configured to sense a fuel pressure at the outlet;

sensing the fuel pressure at the outlet with the sensor; and

only actuating the valve element when the fuel pressure at the outlet is a negative relative pressure by retracting the armature such that the valve element is spaced from the valve seat and fuel may flow through the valve seat.

13. The method of claim **12**, further comprising actuating the valve element when the fuel pressure at the outlet is not a negative relative pressure by extending the armature such that the valve element bears on the valve seat to inhibit or prevent fuel flow through the valve seat.

14. The method of claim **12**, further comprising comparing the sensed fuel pressure at the outlet to a predetermined threshold to enable a known flow rate of fuel through the fuel metering valve.

15. The method of claim **12**, wherein actuating the valve element when the fuel pressure at the outlet is a negative relative pressure is further dependent on a duration of negative relative pressure at the outlet.

16. The method of claim **12**, further comprising delivering fuel to the inlet of the fuel metering valve by:

providing a fuel delivery system upstream of the fuel metering valve, the fuel delivery system having:

a chamber to which fuel is delivered in fluid communication with the inlet of the fuel metering valve,

a valve assembly controlling fluid flow into the chamber, the valve assembly including a valve element associated with a valve seat so that a portion of the valve element is selectively engageable with the valve seat to prevent fluid flow through the valve seat, and

a float disposed in the chamber that moves the valve element relative to the valve seat, the float being buoyant and coupled with the valve element, the float moving in response to changes in a fuel level in the chamber.

17. The method of claim **16**, wherein delivering fuel to the inlet of the inlet of the fuel metering valve includes:

at a maximum level of fuel in the chamber, buoying the float to a position in the chamber where the valve element is closed against the valve seat, preventing fluid flow through the valve seat, and

as fuel is discharged from the chamber, buoying the float in response to a lower fuel level in the chamber, thereby moving to a position in the chamber where the valve element is spaced away from the valve seat, enabling fluid flow through the valve seat.

18. The method of claim **16**, further comprising controlling the venting of gasses from the chamber by providing a venting system, the venting system having a vent valve including a valve element that is moved relative to a valve seat to selectively permit fluid flow through the vent valve to facilitate fuel flow from the chamber to the fuel metering valve.

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