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**Primus et al.**

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(54) **FUEL INJECTOR FOR GASEOUS FUEL AND VALVE ASSEMBLY FOR THE SAME**


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***F02M 21/02*** (2006.01)

(52) **U.S. Cl.**
CPC .... ***F02M 21/0275*** (2013.01); ***F02M 21/0254*** (2013.01); ***F02M 21/0257*** (2013.01)

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See application file for complete search history.


(56) **References Cited**

U.S. PATENT DOCUMENTS


| | | | |
|---|---|---|---|
| 6,065,692 | A | 5/2000 | Brinn, Jr. |
| 6,182,943 | B1 | 2/2001 | Steinruck et al. |
| 8,316,825 | B1 | 11/2012 | French, III |
| 9,453,486 | B1 | 9/2016 | Hornby et al. |
| 9,464,729 | B2 | 10/2016 | Robertson, III |
| 9,909,537 | B2 | 3/2018 | Hamada et al. |
| 10,364,758 | B2 | 7/2019 | Czimmek et al. |
| 2006/0060675 | A1 | 3/2006 | Cooke et al. |

(Continued)

FOREIGN PATENT DOCUMENTS

| | | | | |
|---|---|---|---|---|
| CA | 2771996 C | | 3/2011 | |
| CN | 103154490 A | * | 6/2013 | ......... F02M 21/0254 |

(Continued)

OTHER PUBLICATIONS

International Search Report and Written Opinion date mailed Aug. 23, 2024; PCT International Patent Application No. PCT/US24/19360, 11 pgs.


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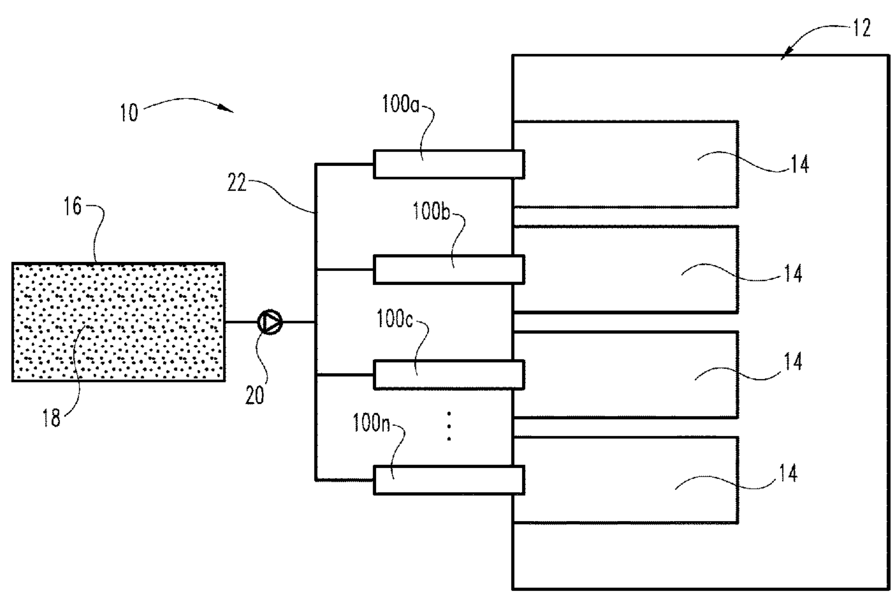
(57) **ABSTRACT**


A fuel injector for gaseous fuel is provided. The fuel injector includes a valve assembly with a fuel flow valve and a second valve. The fuel flow valve is actively controlled to permit and prohibit gaseous fuel flow through the fuel injector. The second valve is spaced from the fuel flow valve and passively controlled to open in response to the gaseous fuel flow though the fuel flow valve, and to close when the gaseous fuel flow is terminated by closing the fuel flow valve.


**20 Claims, 6 Drawing Sheets**



(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | | |
|---|---|---|---|---|
| 2009/0008480 | A1 | 1/2009 | Cooke | |
| 2015/0267659 | A1 * | 9/2015 | Jaegle | F02M 51/061 239/585.5 |
| 2020/0116113 | A1 | 4/2020 | Pirkl et al. | |
| 2024/0344489 | A1 | 10/2024 | Primus et al. | |

FOREIGN PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| CN | 105986937 | B | 10/2016 |
| CN | 106089500 | A | 11/2016 |
| DE | 102013222030 | A1 | 4/2015 |
| DE | 102021110884 | A1 | 11/2022 |
| EP | 3153701 | B1 | 12/2018 |
| WO | 98/26168 | | 6/1998 |
| WO | 2022171574 | A1 | 8/2022 |
| WO | 2024/220171 | A1 | 10/2024 |

* cited by examiner

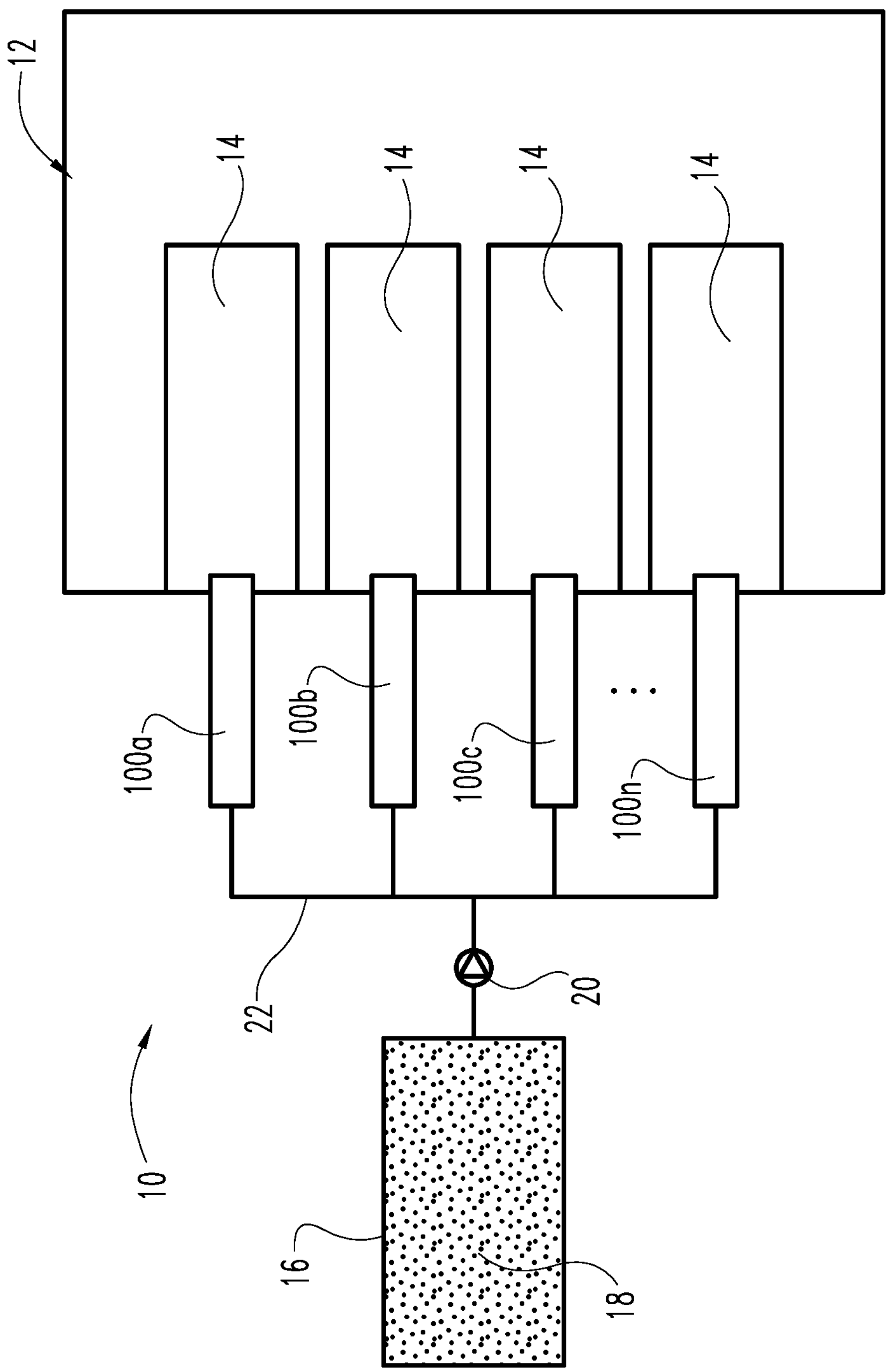
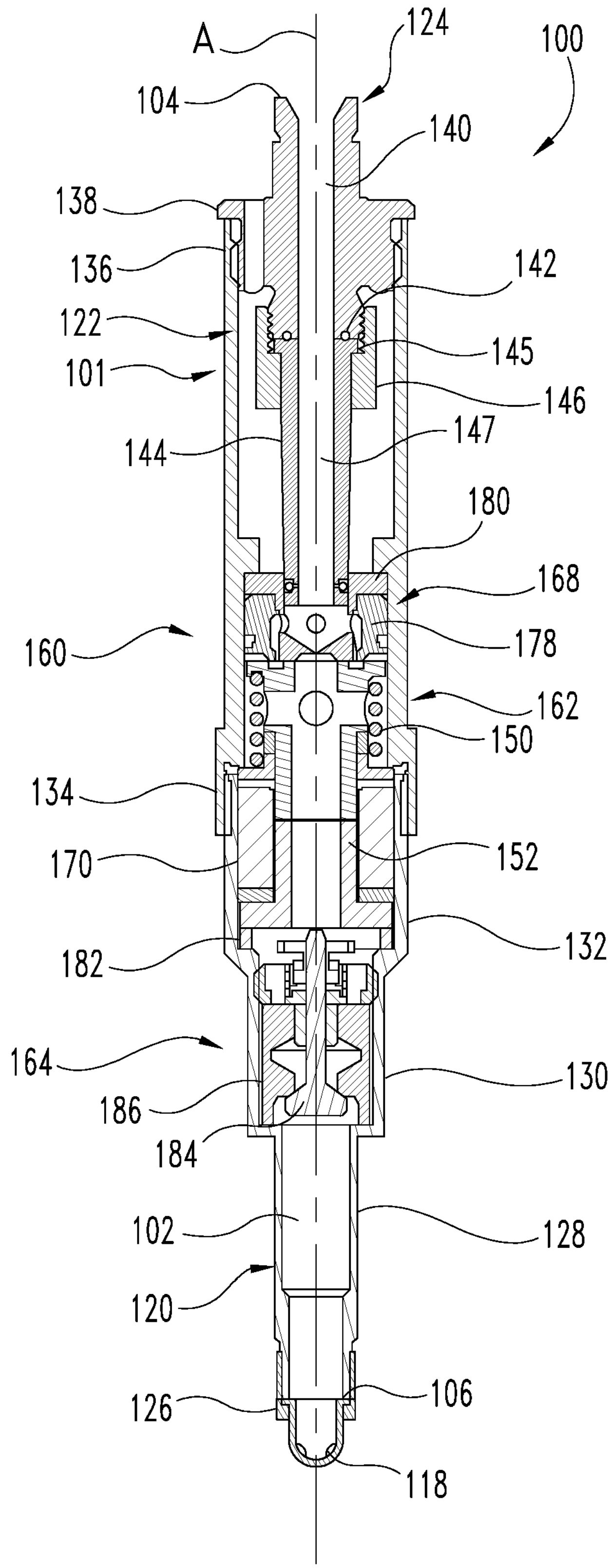



*Fig. 1*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168
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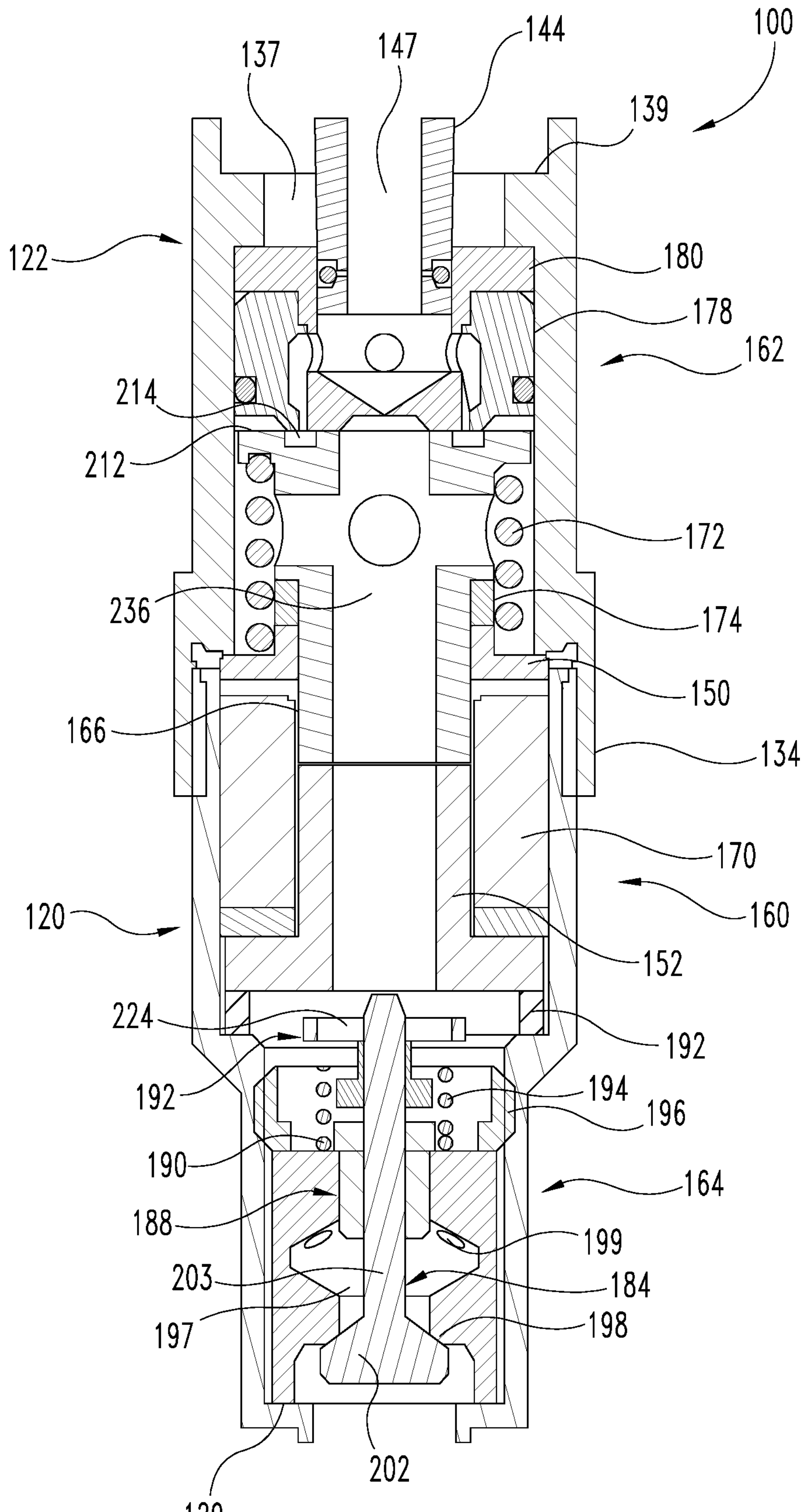
118

Fig. 2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192
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196
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164
188
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203
184
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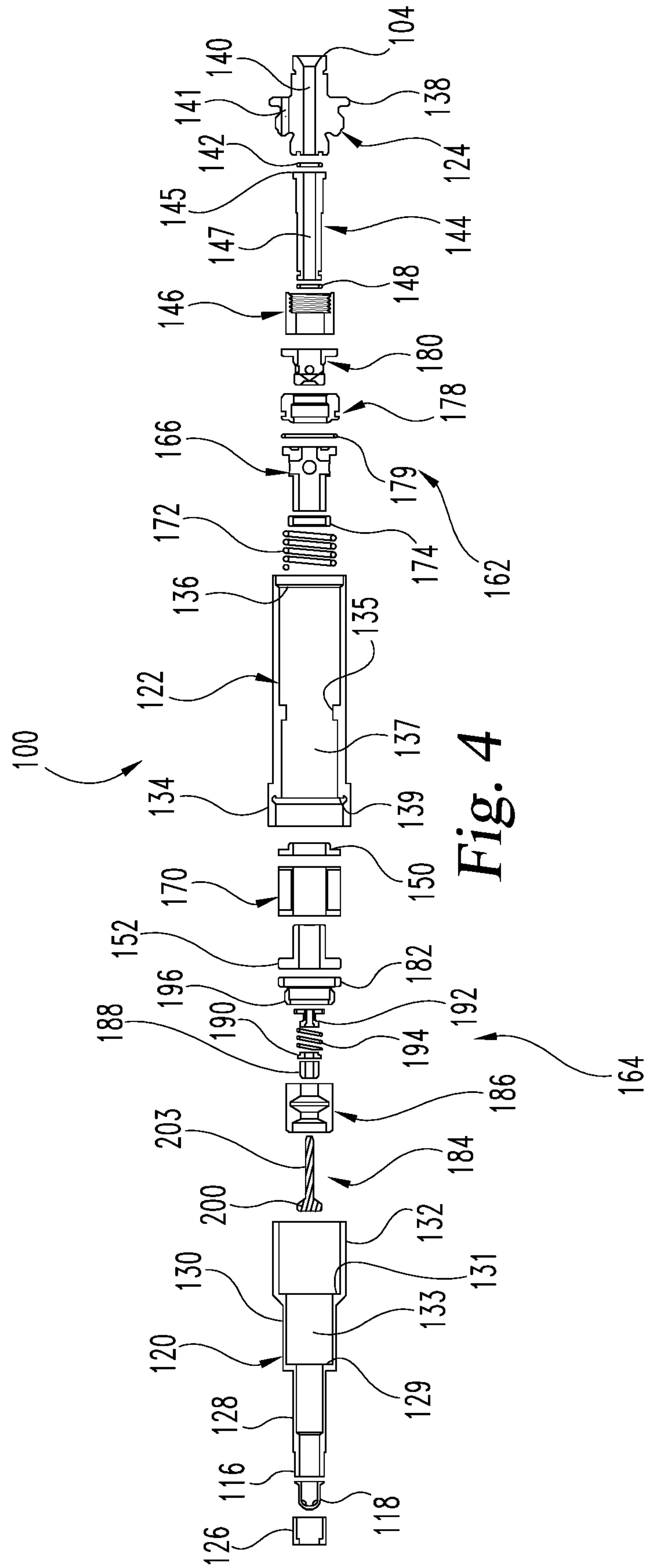
202
129

Fig. 3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178
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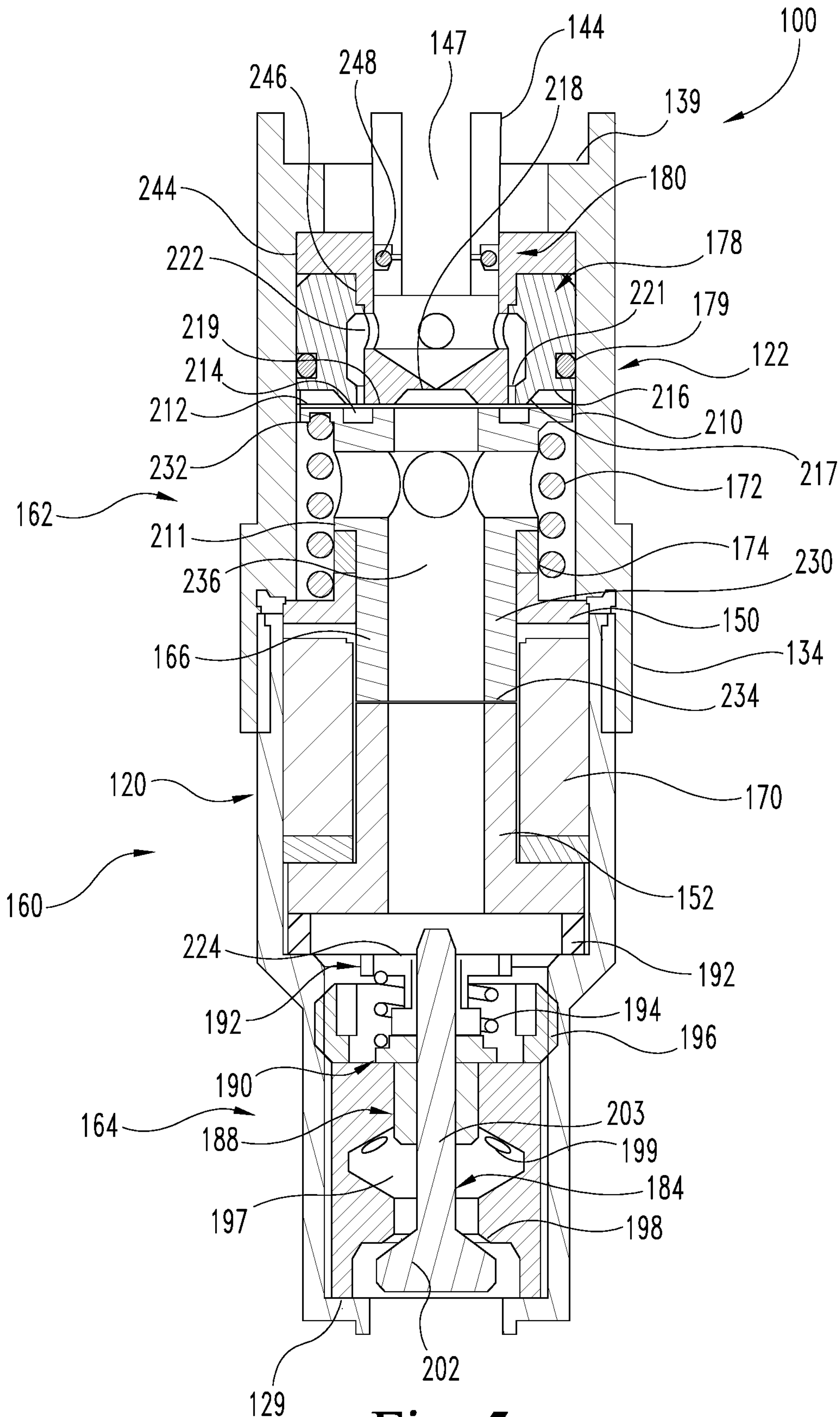
137
100
134
139
150
170
152
182
196
192
190
194
188
164
186
203
184
200
132
131
130
133
120
129
128
116
118
126

Fig. 4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172
162
211
174
236
230
150
166
134
234
120
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196
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203
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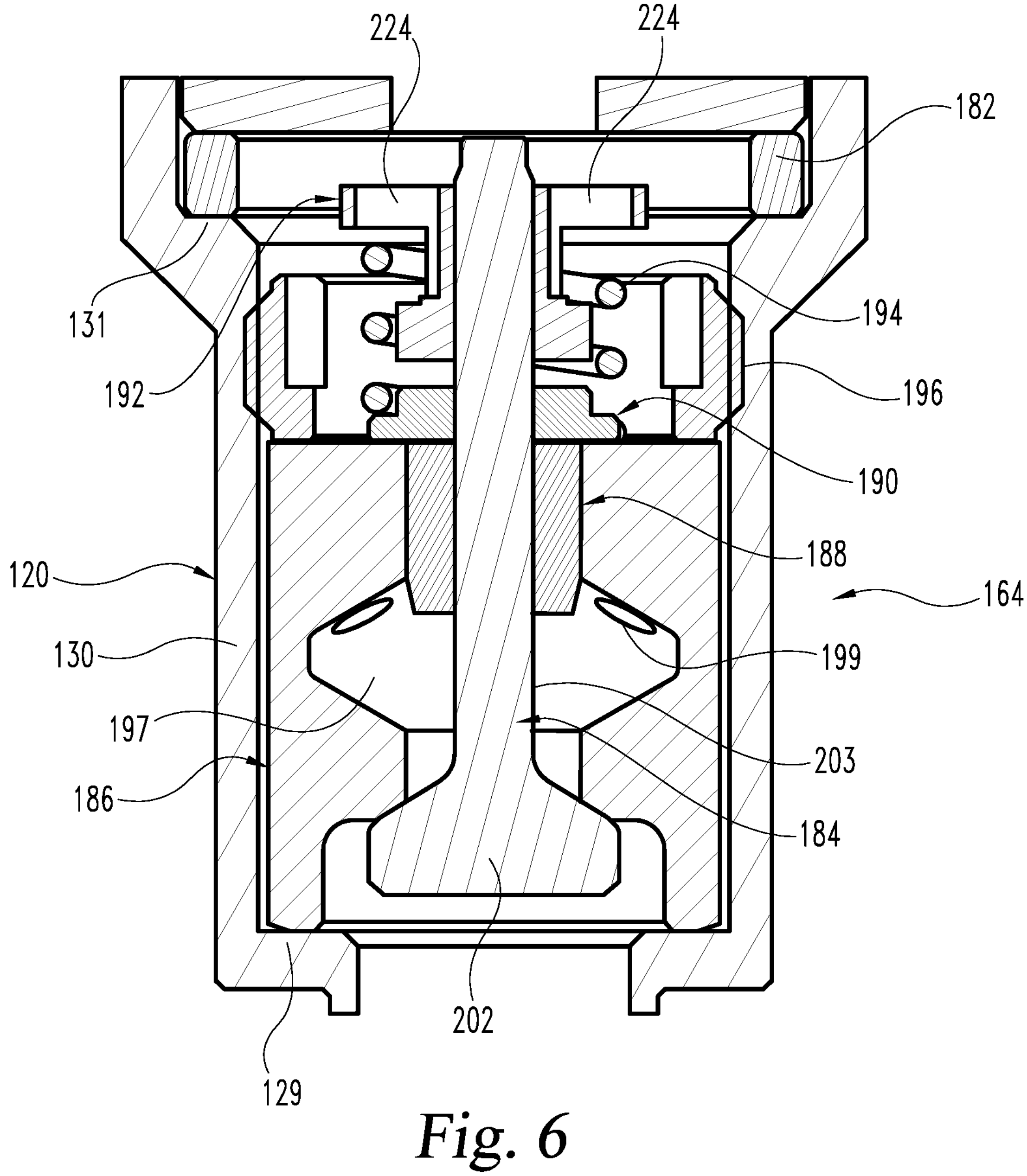
199
184
197
198
202
129

Fig. 5


224
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182
131
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192
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188
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164
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199
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203
186
184
202
129

*Fig. 6*

# FUEL INJECTOR FOR GASEOUS FUEL AND VALVE ASSEMBLY FOR THE SAME

## CROSS-REFERENCE TO RELATED APPLICATION

The present application claims the benefit of the filing date of U.S. Provisional Application Ser. No. 63/496,536 filed Apr. 17, 2023, which is incorporated herein by reference.

## FIELD OF THE DISCLOSURE

The present disclosure relates generally to a fuel injector for providing gaseous fuel for an internal combustion engine and, more particularly, to a valve assembly arrangement for a fuel injector for gaseous fuel.

## BACKGROUND

Fuel injectors for gaseous fuel injection are subject to extreme conditions due to pressure temperature changes. When combustion of the gaseous fuel occurs in the combustion chamber, high temperature combustion gases can flow back into the fuel injector, causing a rapid change in temperature and applied force to the injector components. The potential for wide variations in temperature and pressure conditions within the fuel injector can reduce fuel injector life and robustness. Therefore, there remains a need for the unique apparatuses, systems, and techniques disclosed herein.

## DISCLOSURE OF ILLUSTRATIVE EMBODIMENTS

For the purposes of clearly, concisely and exactly describing illustrative embodiments of the present disclosure, the manner, and process of making and using the same, and to enable the practice, making and use of the same, reference will now be made to certain exemplary embodiments, including those illustrated in the figures, and specific language will be used to describe the same. It shall nevertheless be understood that no limitation of the scope of the invention is thereby created and that the invention includes and protects such alterations, modifications, and further applications of the exemplary embodiments as would occur to one skilled in the art.

## SUMMARY

The present disclosure includes a valve assembly for a fuel injector of a gaseous fuel injection system for an internal combustion engine. The valve assembly includes a first valve to control the flow of gaseous fuel into the fuel injector, and a second valve spaced longitudinally from the first valve to control the flow of combustion gases from the combustion chamber back into the fuel injector. The ability to control the flow of gaseous fuel from the injector and the flow of combustion gases back into the fuel injector reduces exposure of fuel injector components to temperature changes, improves fuel injector robustness, and increases operating life.

In an embodiment, a fuel injector for providing gaseous fuel to a combustion chamber is provided. The fuel injector includes an elongated injector body defining a longitudinally extending fuel passage therein. The fuel passage extends from a gas inlet end to a gas outlet end of the injector body.



The fuel injector includes a fuel flow valve that is selectively opened and closed to control gaseous fuel flow through the fuel passage to the combustion chamber. The fuel flow valve includes a valve seat that includes a seat passage, and the seat passage is in fluid communication with the fuel passage. The fuel flow valve also includes a plunger that includes a sealing member. The sealing member sealingly engages the valve seat to prevent gaseous fuel from flowing through the seat passage to the gas outlet end of the fuel injector body. The fuel injector also includes an actuator coupled to the plunger. The actuator is operable longitudinally displace the plunger from the valve seat to open the seat passage and permit gaseous fuel flow though the valve seat to the gas outlet end.

In an embodiment, a valve assembly is provided in an axially extending gaseous fuel passage of a fuel injector for providing gaseous fuel to a combustion chamber through a gas outlet end of the fuel injector. The valve assembly includes a first valve in the gaseous fuel passage and a second valve in the gaseous fuel passage. The first valve includes a first valve seat and a first plunger. The first plunger is actuatable between an open position in which the first plunger is axially spaced from the first valve seat to allow gaseous fuel flow through the first valve and a closed position in which the first plunger is in sealing contact with the first valve seat to prevent gaseous fuel flow through the first valve. The second valve is axially spaced from the first valve along the gaseous fuel passage. The second valve includes a second valve seat and a second plunger that engages with the second valve seat to inhibit combustion gases from reaching the first valve. The first plunger is moved toward the gas outlet end to open the first valve and the second plunger is moved toward the gas outlet end to open the second valve.

This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter. Further embodiments, forms, objects, features, advantages, aspects, and benefits shall become apparent from the following description and drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

The description herein makes reference to the accompanying drawings wherein like numerals refer to like parts throughout the several views, and wherein:

FIG. **1** is a schematic view of a fuel injection system.

FIG. **2** is a longitudinal section view illustrating an example fuel injector for an internal combustion engine, according to an embodiment of the present disclosure.

FIG. **3** is an enlarged longitudinal section view of the valve assembly of the fuel injector of FIG. **2** in a closed position.

FIG. **4** is an exploded view of the fuel injector of FIG. **2**.

FIG. **5** is an enlarged longitudinal section view of the first valve of the valve assembly of FIG. **3** in an open position.

FIG. **6** is an enlarged longitudinal section view of the second valve of the valve assembly of FIG. **3** in a closed position.

## DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

With reference to FIG. **1**, there is illustrated a fuel injection system **10** including at least one fuel injector **100***a*, **100***b*, **100***c* . . . **100***n* for a respective combustion chamber **14** of an internal combustion engine **12**. The at least one fuel injector **100***a*, **100***b*, **100***c* . . . **100***n* is in fluid communication with a fuel source **16** containing a gaseous fuel **18**, and a fuel tank/regulator **20** and/or common rail **22** to distribute fuel to the injectors **100***a*, **100***b*, **100***c* . . . **100***n*. Although multiple fuel injectors are shown schematically in FIG. **1**, system **10** may include any number of fuel injectors, including one fuel injector. Pressurized gaseous fuel **18** is supplied to each of the fuel injectors **100***a*, **100***b*, **100***c* . . . **100***n* from the fuel tank/regulator **20**. In the discussion that follows, fuel injectors **100***a*, **100***b*, **100***c* . . . **100***n* are described with reference to a fuel injector **100**, such as shown in FIGS. **2**-**6**.

In an embodiment, the fuel injector **100** provides gaseous fuel to combustion chamber **14**. The fuel injector **100** includes an elongated injector body **101** defining a longitudinally extending fuel passage **102** therein. The fuel passage **102** extends from a gas inlet end **104** to a gas outlet end **106** of the injector body **101**. The fuel injector **100** includes a fuel flow valve **162** that is selectively opened and closed to control gaseous fuel flow through the fuel passage **102** to the combustion chamber **14**. The fuel flow valve **162** includes a valve seat **168** that includes a seat passage **221**, and the seat passage **221** is in fluid communication with the fuel passage **102**. The fuel flow valve **162** also includes a plunger **166** that includes a sealing member **214**. The sealing member **214** sealingly engages the valve seat **168** to prevent gaseous fuel from flowing through the seat passage **221** to the gas outlet end **106** of the fuel injector body **101**. The fuel injector **100** also includes an actuator **170** coupled to the plunger **166**. The actuator **170** is operable longitudinally displace the plunger **166** from the valve seat **168** to open the seat passage **221** and permit gaseous fuel flow though the valve seat **168** to the gas outlet end **106**.

In an embodiment, valve assembly **160** is provided in an axially extending gaseous fuel passage **102** of fuel injector **100** for providing gaseous fuel to combustion chamber **14** through gas outlet end **106** of the fuel injector **100**. The valve assembly **160** includes a first valve **162** in the gaseous fuel passage **102** and a second valve **164** in the gaseous fuel passage **102**. The first valve **162** includes a first valve seat **168** and a first plunger **166**. The first plunger **166** is actuatable between an open position in which the first plunger **166** is axially spaced from the first valve seat **168** to allow gaseous fuel flow through the first valve **162** and a closed position in which the first plunger **166** is in sealing contact with the first valve seat **168** to prevent gaseous fuel flow through the first valve **162**. The second valve **164** is axially spaced from the first valve **162** along the gaseous fuel passage **102**. The second valve **164** includes a second valve seat **186** and a second plunger **184** that engages with the second valve seat **186** to inhibit combustion gases from reaching the first valve **163**. The first plunger **166** is moved toward the gas outlet end **106** to open the first valve **162**, and the second plunger **184** is moved toward the gas outlet end **106** to open the second valve **164**.

Referring to FIGS. **2**-**6**, injector body **101** extends along a central longitudinal axis A and includes fuel passage **102** that is defined by the injector body **101** from gas inlet end **104** to gas outlet end **106**. The longitudinally extending fuel passage **102** receives valve assembly **160** and a valve actuator **170** therein to control gaseous fuel flow from gas inlet end **104** to gas outlet end **106**, and to control combustion gas flow from gas outlet end **106** into fuel passage **102**. In the discussion that follows, "proximal" or "proximally" refer to an axial location or upstream direction toward gas inlet end **104**, and "distal" or "distally" refers to an axial location or downstream direction toward gas outlet end **106**.

Injector body **101** can be comprised of multiple parts that are coupled to one another to form injector body **101**. In the illustrated embodiment, injector body **101** includes an outlet part **120** extending from gas outlet end **106**, an inlet part **124** extending from gas inlet end **104**, and a transition part **122** that connects outlet part **120** and inlet part **124**. Other embodiments contemplate an injector body **101** made from a single body part, from two body parts, or from more than two body parts.

Inlet part **124** includes a flange **138** to facilitate mounting of the fuel injector **100** on the engine **12**. A feature may also be provided on the injector body **101** to facilitate injector mounting. Inlet part **124** also includes a gas passage **140** for receiving gaseous fuel flow into passage **102** of injector body **101**. Inlet part **124** may also include a bore **141** for receiving wires (not shown) that are coupled to valve actuator **170**.

A nozzle **118** is engaged to the end of outlet part **120** with a nozzle coupler **126**. In other embodiments, a nozzle coupler **126** is not provided. Nozzle **118** may include one or more holes arranged to divert gaseous fuel flow in a desired direction or flow pattern into the combustion chamber **14**. Nozzle **118** can be configured to optimize combustion of the gaseous fuel based on the combustion conditions of engine **12**. Nozzle **118** is always open to allow the gaseous fuel flow to exit fuel passage **102**, which also allows combustion gases to enter fuel passage **102**.

In the illustrated embodiment, the outlet part **120** includes an interior **133** with three stepped regions **128**, **130**, **132**. First stepped region **128** is adjacent to gas outlet end **106** and is coupled to nozzle **118**. First stepped region **128** is smallest in diameter, and receives gaseous fuel flow from the opened second valve **164**. In addition, combustion gases enter first stepped region **128** from the combustion chamber **14**, as discussed further below.

Second valve **164** is housed primarily in second stepped region **130**, and the fuel flow valve, also referred to as first valve **162**, is partially housed in third stepped region **132**. Transition part **122** is also engaged to third stepped region **132**. In the illustrated embodiment, transition part **122** includes an insert region **134** that is configured to receive and be engaged to third stepped region **132**, such as by a threaded, welded, press-fit, or other suitable engagement. The connection between outlet part **120** and transition part **122** can be sealed with injector body seal (not shown), such as an elastomeric ring. Transition part **122** also includes a receiving region **136** that receives and engages the inlet part **124**, such as by a threaded, welded, press-fit, or other suitable engagement. Flange **138** of inlet part **124** can abut the outer proximal end of transition part **122** at receiving region **136**.

Fuel injector **100** includes a tube **144** that is located in interior **137** of transition part **122**. Tube **144** is engaged end-to-end with inlet part **124** with a tube coupler **146**. Any type of coupling device for tube coupler **146** is contemplated. In the illustrated embodiment, tube coupler **146** includes internal threads to threadingly engage corresponding threads on inlet part **124**, and an internal collar to support a flanged proximal end **145** of tube **144**. As a result, tube **144** is axially fixed in body **101**. An end seal **142** can be provided in a groove in the end face of inlet part **124** that seals against the abutting end of tube **144**. Tube **144** includes a bore **147** that defines a part of fuel passage **102** from inlet part **124** to valve assembly **160**.

Actuator **170** is located in interior **133** of third stepped region **132** of outlet part **120**. In an embodiment, actuator **170** is an electronic actuator, such as a solenoid, that is electronically controlled by energizing and de-energizing a magnetic coil to actively and selectively control opening and closing for first valve **162** of valve assembly **160**. An actuator retainer **150** is secured within insertion region **134** of transition part **122**. Actuator mount **152** is positioned between actuator **170** and a spacer **182**. Spacer **182** is located on lip **131** at the junction between stepped regions **130**, **132** of outlet part **120**. Plunger **166** extends into actuator **170** in an end-to-end arrangement with actuator mount **152**.

First plunger **166** extends proximally from a distal or second end **234** within actuator **170** out of actuator **170** to a proximal or first end **232** in interior **137** of transition part **122**. First plunger **166** is engaged to, and axially movable toward gas outlet end **106**, by actuation of actuator **170**. In an embodiment, first plunger **166** is an armature plunger. In an embodiment, first plunger **166** is comprised entirely of the same material. First end **232** of plunger **166** is biased into sealing engagement with first valve seat **168** by a first valve spring **172**.

First valve spring **172** contacts a distally facing surface of plunger **166** formed by a plunger flange **210** at or near first end **232**. First valve spring **172** also contacts a proximal side of actuator retainer **150** to bias first end **232** toward first valve seat **168**. A buffer **174** is also provided between the actuator retainer **150** and a distally facing surface an intermediate lip **211** of plunger **166**. Buffer **174** can be used to control the amount of axial movement of first plunger **166** in response to actuation by actuator **170**. For example, when first valve **162** is closed, buffer **174** does not occupy the entire space between intermediate lip **211** of plunger **166** and actuator retainer **150**, such as shown in FIG. **3**. When first valve **162** is opened as shown in FIG. **5**, first valve spring **172** compresses and the first plunger **166** translates axially in the distal direction until buffer **174** contacts each of intermediate lip **211** and the actuator retainer **150** to limit or prevent further axial displacement of first plunger **166** in the distal direction.

First valve seat **168** includes an outer seat member **178** and an inner seat member **180** located in interior **137** of transition part **122**. Outer seat member **178** is sealingly engaged in with the inner wall of transition part **122** surrounding interior **137** with seat seal **179**. Inner seat member **180** is located at least partially within outer seat member **178**. Inner seat member **180** is supported and/or sealed to the distal end of tube **144**, and in abutting engagement with a ledge **139** of transition part **122** that projects into interior **137**. In the illustrated embodiment, first valve seat **168** is comprised of two separate members, but could also be made using a single member.

Second valve **164** includes second valve seat **186** supported on the proximally facing lip **129** between first stepped region **128** and second stepped region **130**. A stopper **196** is engaged to outlet part **120** in stepped region **130** to secure second valve seat **186** against lip **129**. Second valve seat **186** includes a cylindrical body having an inner bore **197** with a seat portion **198** projecting into inner bore **197**. Second plunger **184** includes a head **202** that contacts seat portion **198** in the closed position of second valve **164**, and head **202** is moved distally away from seat portion **198** to open second valve **164**.

Second plunger **184** includes a stem **203** extending axially from head **202** through inner bore **197** toward first valve **162**. Stem **203** includes a guide bushing **188** extending therearound. Other embodiments contemplate guide bushing **188** is omitted and plunger **184** is guided by second valve seat **186**. A plunger stop **190** is positioned on top of valve seat **186** around stem **203**. Guide bushing **188** is axially fixedly within second valve seat **186**, and stem **203** can move axially relative to guide bushing **188** and plunger stop **190**.

The proximal end of stem **203** of second plunger **184** is coupled to a collar **192**, such as with a press fit or other fixed attachment, and collar **192** sets the stroke of second plunger **184**. Collar **192** is biased proximally by a second valve spring **194** between collar **192** and plunger stop **190** so that head **202** of second plunger **184** is normally biased against seat **198**. In an embodiment, head **202** and seat **198** are both made of metal material that is capable of withstanding temperatures produced by the combustion gases flowing from the combustion chamber into fuel passage **102**. The metal-to-metal interface need not provide a seal that prevents all leakage of combustion gases through second valve **164**, but is sufficient to limit exposure of first valve **162** to combustion temperatures.

Since second valve **164** is passively controlled by second valve spring **194** based on whether or not there is gaseous fuel flow through first valve **162**, and since second valve **164** is not actuated by actuator **170** or connected to any components of first valve **162**, the axial location of second valve **164** within body **101** can be optimized to balance temperature and gas mixing conditions for first valve **162** and second valve **164** during operation of the fuel injector **100** depending on combustion conditions expected for the fuel, combustion parameters, etc.

In response to gaseous flow being introduced from first valve **162**, second valve spring **194** compresses due forces acting on collar **192** and head **202**, which cause second plunger **184** to be displaced distally to an open position, as shown in FIG. **5**. Stem **202** moves axially through guide bushing **188** until collar **192** contacts plunger stop **190**, limiting the amount of distal displacement of second plunger **184**. In the open position, head **202** is spaced distally from seat portion **198** to form a gap or passage for gaseous fuel flow to the combustion chamber **14**.

During operation of fuel injector **100**, gaseous fuel enters fuel passage **102** at gas inlet end **104**. The gaseous fuel is prevented from flowing through fuel passage **102** by the first valve **162** of valve assembly **160** being in a closed position by first valve spring **172**, as shown in FIG. **3**. In addition, second valve **164** of valve assembly **160** is normally closed by second valve spring **194** so that combustion gases cannot flow into fuel passage **102** to reach first valve **162**, as shown in FIGS. **3** and **6**.

As discussed above, first valve spring **172** biases the first plunger **166** proximally into contact with the first valve seat **168**. First plunger **166** includes an end face **212** that sealingly contacts the first valve seat **168** with the first valve **162** in the closed position. The end face **212** including an elastomeric sealing member **214** that is engaged at two locations by the axial protrusions **217**, **219** of first valve seat **168** in the closed position of the first valve **162**. Sealing member **214** can be, for example, a ring-shaped sealing member that is embedded or inset into a recess in end face **212** of plunger **166**.

In the illustrated embodiment, outer seat member **178** includes an outer outlet end **216** with an axial protrusion **217** in sealing contact with the sealing member **214**. In addition, inner seat member **180** includes an inner outlet end **218** with an axial protrusion **219** in sealing contact with the sealing member **214** at a second location that is separate from the first location. In an embodiment, the axial protrusion **217** on outer outlet end **216** and the axial protrusion **219** on inner outlet end **218** form concentric circles that contact sealing member **214** at two different radial locations around the annular sealing member **214**. A seat passage **221** is formed through first seat **164** between axial protrusions **217**, **219** since the inner outlet end **218** of inner seat member **180** is spaced radially inwardly from the outer outlet end **216** of outer seat member **178**. In an embodiment, seat passage **221** is an annular passage formed between inner seat member **180** and outer seat member **178**.

Gaseous fuel provided into fuel passage **102** through gas inlet end **104** flows out of inner seat member **180** through seat member sidewall outlets **222**, and through the space between outer seat member **178** and inner seat member **180** into passage **221**. In an embodiment, the gaseous fuel enters inner seat member **180** from bore **147** of tube **144**, and then exits through a plurality of sidewall outlets **222** of inner seat member **180**. When first valve **162** is closed, first valve spring **172** need only to counteract the force from the fuel pressure that acts on sealing member **214** by the gaseous fuel in passage **221**. As a result, the coil or other mechanism of actuator **170** that displaces first plunger **166** can be reduced in size/force since the gaseous fuel force on first plunger **166** is only created by the gas pressure in passage **221** that acts on the surface area of sealing member **214** between axial protrusions **217**, **219**.

When first valve **162** is opened, gaseous fuel flow exits the passage **221** between the outer inlet end **216** and the inner outlet end **218** due to sealing member **214** of first plunger **166** breaking contact with the axial protrusions **217**, **219** of outer seat member **178** and inner seat member **180**, as shown in FIG. **5**. The gaseous fuel then flows along end face **212** and inner outlet end **218** where it then enters axial passage **236** of plunger **166**. Gaseous fuel from axial passage **236** then flows through an axial passage of actuator mount **152** and then flows through optional axial bores **224** defined by collar **192** and around collar **192** of second valve **164** into second valve **164**.

The gaseous fuel pressure acting on head **202** of second plunger **184** compresses second valve spring **192** and distally displaces second plunger **184** to disengage it from seat portion **198**, opening second valve **164** as shown in FIG. **5**. The amount of distal displacement of second plunger **184** is limited by collar **192** contacting the plunger stop **190** in second valve seat **186**. Gaseous fuel flows through one or more axial seat bores **199** formed through second valve seat **186** that open into inner bore **197**.

When gaseous fuel flow is terminated, the actuator **170** is deactivated and first valve spring **172** returns first plunger **166** into sealing engagement with first valve seat **168**. The termination of gaseous fuel flow also allows second valve spring **194** to return second plunger **184** into engagement with second valve seat **186**. In the closed position, the second valve **164** prevents, or substantially prevents, combustion gases from reaching first valve **162**. As a result, first valve **162** is subject to less severe temperature and pressure changes than would be created if second valve **164** were omitted.

In an embodiment the first plunger **166** includes an elongated cylindrical plunger body **230** axially extending from a first end **232** to an opposite second end **234**. The second end **234** is engaged to actuator **170**, and actuator **170** is operable to move the first plunger **166** axially toward and away from the first valve seat **168**. The first end **234** includes end face **212** with sealing member **214** that sealingly contacts the first valve seat **168** while the first valve **162** is in the closed position.

In an embodiment, the elongated body **230** of the first plunger **166** includes an axial passage **236** that opens at the proximal first end **232** of the first plunger **166** for receiving gaseous fuel flow when first valve **162** is open. Plunger body **230** also includes plunger flange **210** at first end **232** and intermediate lip **211**. Axial passage **236** extends through second end **234** of plunger body **230** and opens into the axial passage of actuator mount **152**. Sealing member **214** extends around the opening of axial passage **236** in end face **212**.

In an embodiment, first valve seat **168** includes an inner seat member **180** having a cylindrical body **246** extending from inner outlet end **218** to an opposite flanged second end **244**. The inner outlet end **218** includes axial protrusion **219** that contacts the end face **212** of the first plunger **166** in the closed position of the first valve **162**. The cylindrical body **246** extends around an inner bore **248** of the inner seat member **180**, and the inner bore **248** is closed at the inner outlet end **218** of the first cylindrical body **240**, and is axially open at the flanged second end **244** of the cylindrical body **240**.

The cylindrical body **246** includes a plurality of sidewall outlets **222** distributed around the inner seat member **180**. The plurality of sidewall outlets **222** allow gaseous fuel flow from the gas inlet end **104** to flow into passage **221**, where it can be passed through first valve **162** when first valve **162** is opened. The second valve seat **186** of the second valve **164** includes an axial inner bore **197** to receive gaseous fuel flow from first valve **162** through axial seat bores **199**. The gaseous fuel flow received from the axial passage **236** of plunger **166** displaces the second plunger **184** from the second valve seat **186** to open second valve **164**. When first valve **162** is closed, the second valve spring **194** automatically closes second valve **164** to isolate combustion gases in fuel passage **102** distally of second valve **164**.

Further written description of a number of example embodiments shall now be provided. According to one aspect of the present disclosure, a fuel injector is provided for gaseous fuel to a combustion chamber. The fuel injector includes an elongated injector body defining a longitudinally extending fuel passage therein. The fuel passage extends from a gas inlet end to a gas outlet end of the injector body. The fuel injector also includes a fuel flow valve that is selectively opened and closed to control gaseous fuel flow through the fuel passage to the combustion chamber. The fuel flow valve includes a valve seat that includes a seat passage, a plunger, and an actuator. The seat passage is in fluid communication with the fuel passage. The plunger includes a sealing member. The sealing member sealingly engages the valve seat to prevent gaseous fuel from flowing through the seat passage to the gas outlet end of the fuel injector body. The actuator is coupled to the plunger and is operable longitudinally displace the plunger from the valve seat to open the seat passage and permit gaseous fuel flow though the valve seat to the gas outlet end.

In an embodiment, the fuel injector includes a second valve configured to control combustion gas flow from the combustion chamber into the fuel passage through the gas outlet end. The second valve is downstream of the plunger of the fuel flow valve.

In an embodiment, the second valve includes a second plunger that is biased to a closed position, and the second plunger is moved from a closed position to an open position by the gaseous fuel flow through the fuel flow valve.

In an embodiment, the plunger of the fuel flow valve and the second plunger each move toward the gas outlet end to open the fuel flow valve and the second valve, respectively.

In an embodiment, the fuel flow valve includes a valve spring that biases the plunger into sealing engagement with the valve seat. In an embodiment, the plunger of the fuel flow valve and the actuator are both downstream of the valve seat.

In an embodiment, the plunger includes an end face that faces the valve seat, and the sealing member is located on the end face in order to sealingly engage the valve seat with the fuel flow valve in the closed position.

In an embodiment, the end face of the plunger faces the gas inlet end of the fuel injector body, and the sealing member is an elastomeric ring on the end face of the plunger.

In an embodiment, the valve seat of the fuel flow valve includes an outer seat member, an inner seat member, and a seat passage. The outer seat member includes an outer inlet end in contact with the sealing member. The inner seat member is located at least partially within the outer seat member, and the inner seat member includes an inner inlet end in contact with the sealing member. The seat passage is between the outer seat member and the inner seat member.

In an embodiment, the seat passage is an annular opening between the inner seat member and the outer seat member. The sealing member spans the seat passage between the inner seat member and the outer seat member.

In an embodiment, the outer seat member includes a first axial protrusion that contacts the sealing member in the closed position of the fuel flow valve. The inner seat member includes a second axial protrusion that contacts the sealing member in the closed position of the fuel flow valve.

In an embodiment, the seat passage extends between the first axial protrusion and the second axial protrusion.

In an embodiment, the fuel injector includes a nozzle on the gas outlet end of the injector body. The nozzle is configured to divert gaseous fuel flow through the gas outlet end into the combustion chamber.

According to another aspect of the present disclosure, a valve assembly in an axially extending gaseous fuel passage of a fuel injector for providing gaseous fuel to a combustion chamber through a gas outlet end of the fuel injector is provided. The valve assembly includes a first valve in the gaseous fuel passage and a second valve in the gaseous fuel passage. The first valve includes a first valve seat and a first plunger. The first plunger is actuatable between an open position in which the first plunger is axially spaced from the first valve seat to allow gaseous fuel flow through the first valve and a closed position in which the first plunger is in sealing contact with the first valve seat to prevent gaseous fuel flow through the first valve. The second valve is axially spaced from the first valve along the gaseous fuel passage. The second valve includes a second valve seat and a second plunger that engages with the second valve seat to inhibit combustion gases from reaching the first valve. The first plunger is moved toward the gas outlet end to open the first valve and the second plunger is moved toward the gas outlet end to open the second valve.

In an embodiment, the second plunger moves axially away from the first valve and disengages the second valve seat in response to gaseous fuel flow through the first valve.

In an embodiment, the first valve includes a first valve spring that biases the first plunger toward the first valve seat in a direction opposite the gas outlet end of the fuel injector.

In an embodiment, the second valve includes a second valve spring that biases the second plunger toward the second valve seat in a direction opposite the gas outlet end of the fuel injector.

In an embodiment, the valve assembly includes an electronic actuator operable to actuate the first plunger between the open position and the closed position. The electronic actuator is located between the first valve and the second valve and the second plunger is not actuatable by the electronic actuator.

In an embodiment, the second valve seat includes a plurality of axial seat bores to receive gaseous fuel flow from the first valve, and a seat portion downstream of the plurality of axial seat bores. The second plunger engages the seat portion in the closed position of the second valve.

In an embodiment, the first valve seat includes an outer seat member, an inner seat member, and a seat passage. The outer seat member includes an outer inlet end in sealing contact with the first plunger while the first valve is in the closed position. The inner seat member is located at least partially within the outer seat member. The inner seat member includes an inner inlet end in sealing contact with the second plunger while the first valve is in the closed position. The seat passage extends between the outer seat member and the inner seat member. The seat passage is configured to allow gaseous fuel flow through the first valve seat while the first valve is in the open position.

While illustrative embodiments of the disclosure have been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only certain exemplary embodiments have been shown and described and that all changes and modifications that come within the spirit of the claimed inventions are desired to be protected. It should be understood that while the use of words such as preferable, preferably, preferred or more preferred utilized in the description above indicates that the feature so described may be more desirable, it nonetheless may not be necessary and embodiments lacking the same may be contemplated as within the scope of the invention, the scope being defined by the claims that follow. In reading the claims, it is intended that when words such as "a," "an," "at least one," or "at least one portion" are used there is no intention to limit the claim to only one item unless specifically stated to the contrary in the claim. When the language "at least a portion" and/or "a portion" is used the item can include a portion and/or the entire item unless specifically stated to the contrary.

What is claimed is:

**1**. A fuel injector for providing gaseous fuel to a combustion chamber, the fuel injector comprising:

an elongated injector body defining a longitudinally extending fuel passage therein, the fuel passage extending from a gas inlet end to a gas outlet end of the injector body;

a fuel flow valve that is selectively opened and closed to control gaseous fuel flow through the fuel passage to the combustion chamber, wherein the fuel flow valve includes:

a valve seat that includes a seat passage, the seat passage in fluid communication with the fuel passage, wherein the valve seat includes an outer seat member including an outer inlet end, an inner seat member including an inner inlet end and located at least partially within the outer seat member, and the seat passage is between the outer seat member and the inner seat member; and

a plunger including a sealing member, wherein the sealing member sealingly engages the valve seat to prevent gaseous fuel from flowing through the seat passage to the gas outlet end of the fuel injector body; and

an actuator coupled to the plunger, wherein the actuator is operable longitudinally displace the plunger from the valve seat to open the seat passage and permit gaseous fuel flow though the valve seat to the gas outlet end.

**2**. The fuel injector of claim **1**, further comprising:

a second valve configured to control combustion gas flow from the combustion chamber into the fuel passage through the gas outlet end, wherein the second valve is downstream of the plunger of the fuel flow valve.

**3**. The fuel injector of claim **2**, wherein:

the second valve includes a second plunger that is biased to a closed position; and

the second plunger is moved from a closed position to an open position by the gaseous fuel flow through the fuel flow valve.

**4**. The fuel injector of claim **3**, wherein the plunger of the fuel flow valve and the second plunger each move toward the gas outlet end to open the fuel flow valve and the second valve, respectively.

**5**. The fuel injector of claim **1**, wherein the fuel flow valve includes a valve spring that biases the plunger into sealing engagement with the valve seat.

**6**. The fuel injector of claim **1**, wherein the plunger of the fuel flow valve and the actuator are both downstream of the valve seat.

**7**. The fuel injector of claim **1**, wherein the plunger includes an end face that faces the valve seat, and the sealing member is located on the end face in order to sealingly engage the valve seat with the fuel flow valve in the closed position.

**8**. The fuel injector of claim **7**, wherein the end face of the plunger faces the gas inlet end of the fuel injector body, and the sealing member is an elastomeric ring on the end face of the plunger.

**9**. The fuel injector of claim **1**, wherein with the sealing member sealingly engaged to the valve seat:

the outer inlet end of the outer seat member is in contact with the sealing member; and

the inner inlet end of the inner seat member is in contact with the sealing member.

**10**. The fuel injector of claim **9**, wherein:

the seat passage is an annular opening between the inner seat member and the outer seat member; and

the sealing member spans the seat passage between the inner seat member and the outer seat member.

**11**. The fuel injector of claim **10**, wherein:

the outer seat member includes a first axial protrusion that contacts the sealing member in the closed position of the fuel flow valve; and

the inner seat member includes a second axial protrusion that contacts the sealing member in the closed position of the fuel flow valve.

**12**. The fuel injector of claim **11**, wherein the seat passage extends between the first axial protrusion and the second axial protrusion.

**13**. The fuel injector of claim **1**, further comprising a nozzle on the gas outlet end of the injector body, wherein the nozzle is configured to divert gaseous fuel flow through the gas outlet end into the combustion chamber.

**14**. A valve assembly in an axially extending gaseous fuel passage of a fuel injector for providing gaseous fuel to a combustion chamber through a gas outlet end of the fuel injector, the valve assembly comprising:

a first valve in the gaseous fuel passage, the first valve including a first valve seat and a first plunger, wherein the first plunger is actuatable between an open position in which the first plunger is axially spaced from the first valve seat to allow gaseous fuel flow through the first valve and a closed position in which the first plunger is in sealing contact with the first valve seat to prevent gaseous fuel flow through the first valve; and

a second valve in the gaseous fuel passage, the second valve axially spaced from the first valve along the gaseous fuel passage, the second valve including a second valve seat downstream of the first valve seat to receive gaseous fuel flow from the first valve seat when the first plunger is in an open position, the second valve including a second plunger that engages with the second valve seat to inhibit combustion gases from flowing upstream through the second valve to reach the first valve seat, wherein the first plunger is moved toward the gas outlet end to open the first valve and the second plunger is moved toward the gas outlet end to open the second valve.

**15**. The valve assembly of claim **14**, wherein the second plunger moves axially away from the first valve and disengages the second valve seat in response to gaseous fuel flow through the first valve.

**16**. The valve assembly of claim **14**, further comprising a first valve spring that biases the first plunger toward the first valve seat in a direction opposite the gas outlet end of the fuel injector.

**17**. The valve assembly of claim **16**, further comprising a second valve spring that biases the second plunger toward the second valve seat in a direction opposite the gas outlet end of the fuel injector.

**18**. The valve assembly of claim **14**, further comprising an electronic actuator operable to actuate the first plunger between the open position and the closed position, wherein the electronic actuator is located between the first valve and the second valve and the second plunger is not actuatable by the electronic actuator.

**19**. The valve assembly of claim **14**, wherein the second valve seat includes:

a plurality of axial seat bores to receive gaseous fuel flow from the first valve; and

a seat portion downstream of the plurality of axial seat bores, the second plunger engaging the seat portion in the closed position of the second valve.

**20**. A valve assembly in an axially extending gaseous fuel passage of a fuel injector for providing gaseous fuel to a combustion chamber through a gas outlet end of the fuel injector, the valve assembly comprising:

a first valve in the gaseous fuel passage, the first valve including a first valve seat and a first plunger, wherein the first plunger is actuatable between an open position in which the first plunger is axially spaced from the first valve seat to allow gaseous fuel flow through the first valve and a closed position in which the first plunger is in sealing contact with the first valve seat to prevent gaseous fuel flow through the first valve, wherein the first valve seat includes:

an outer seat member, the outer seat member including an outer inlet end in sealing contact with the first plunger while the first valve is in the closed position;

an inner seat member located at least partially within the outer seat member, the inner seat member including an inner inlet end in sealing contact with the second plunger while the first valve is in the closed position; and

a seat passage extends between the outer seat member and the inner seat member, the seat passage configured to allow gaseous fuel flow through the first valve seat while the first valve is in the open position; and a second valve in the gaseous fuel passage, the second valve axially spaced from the first valve along the gaseous fuel passage, the second valve including a second valve seat and a second plunger that engages with the second valve seat to inhibit combustion gases from reaching the first valve, wherein the first plunger is moved toward the gas outlet end to open the first valve and the second plunger is moved toward the gas outlet end to open the second valve.

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