US 20230313713A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2023/0313713 A1

ALI KHAN et al. (43) Pub. Date: Oct. 5, 2023

(54) ENGINE VALVE ASSEMBLY INCLUDING DETENT MECHANISM CONFIGURED TO INCREASE FORCE BIASING VALVE TOWARD CLOSED POSITION WHEN VALVE IS AT OR NEAR CLOSED POSITION

(71) Applicant: **GM GLOBAL TECHNOLOGY OPERATIONS LLC**, Detroit, MI (US)

(72) Inventors: **Maqsood Rizwan ALI KHAN**, Troy, MI (US); **Mark R. CLAYWELL**, Birmingham, MI (US)

(21) Appl. No.: **17/713,707**

(22) Filed: **Apr. 5, 2022**

Publication Classification

(51) **Int. Cl.**

F01L 1/46 (2006.01)

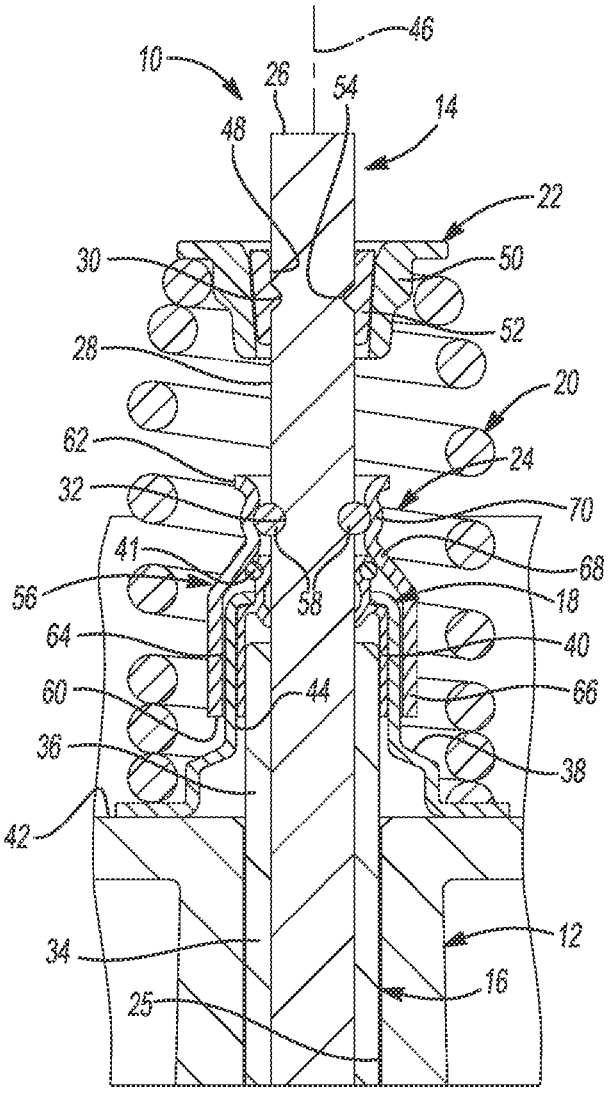
F01L 3/08 (2006.01)

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

CPC ***F01L 1/462*** (2013.01); ***F01L 3/08*** (2013.01)

(57) **ABSTRACT**

A valve assembly includes a valve body defining a bore therein, a valve stem, a spring retainer, a valve spring, and a detent mechanism. The valve stem extends through the bore in the valve body and is adjustable between an open position and a closed position. The spring retainer is spaced apart from the valve body along a longitudinal axis of the valve stem and fixed relative to the valve body. The spring retainer defines a bore through which the valve stem extends. The valve spring is captured between the valve body and the spring retainer and is configured to apply a biasing force to the valve stem that biases the valve stem toward the closed position. The detent mechanism is configured to increase the biasing force applied to the valve stem when the valve stem is in the closed position or within a predetermined distance of the closed position.



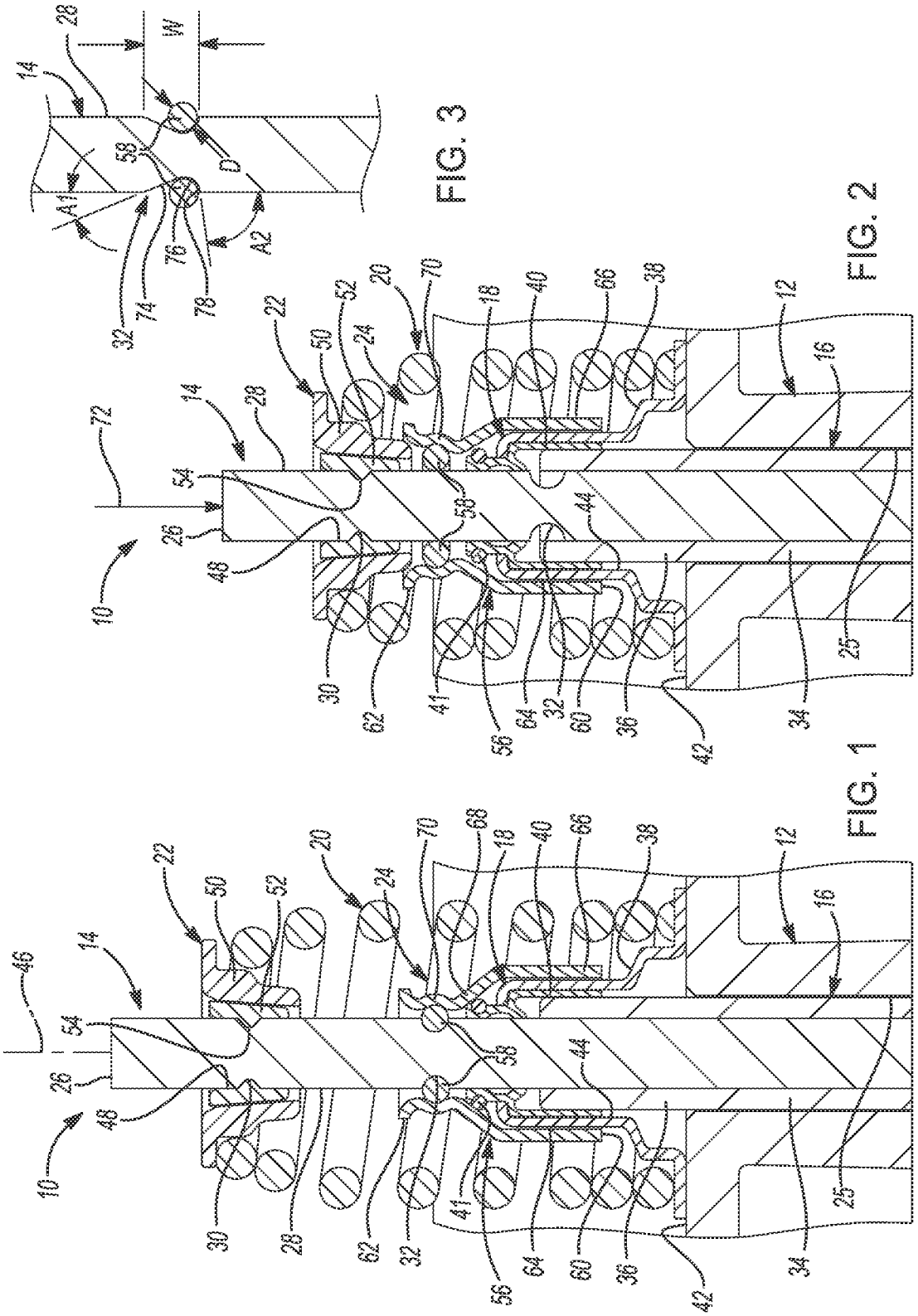


FIG. 3

FIG. 2

FIG. 1

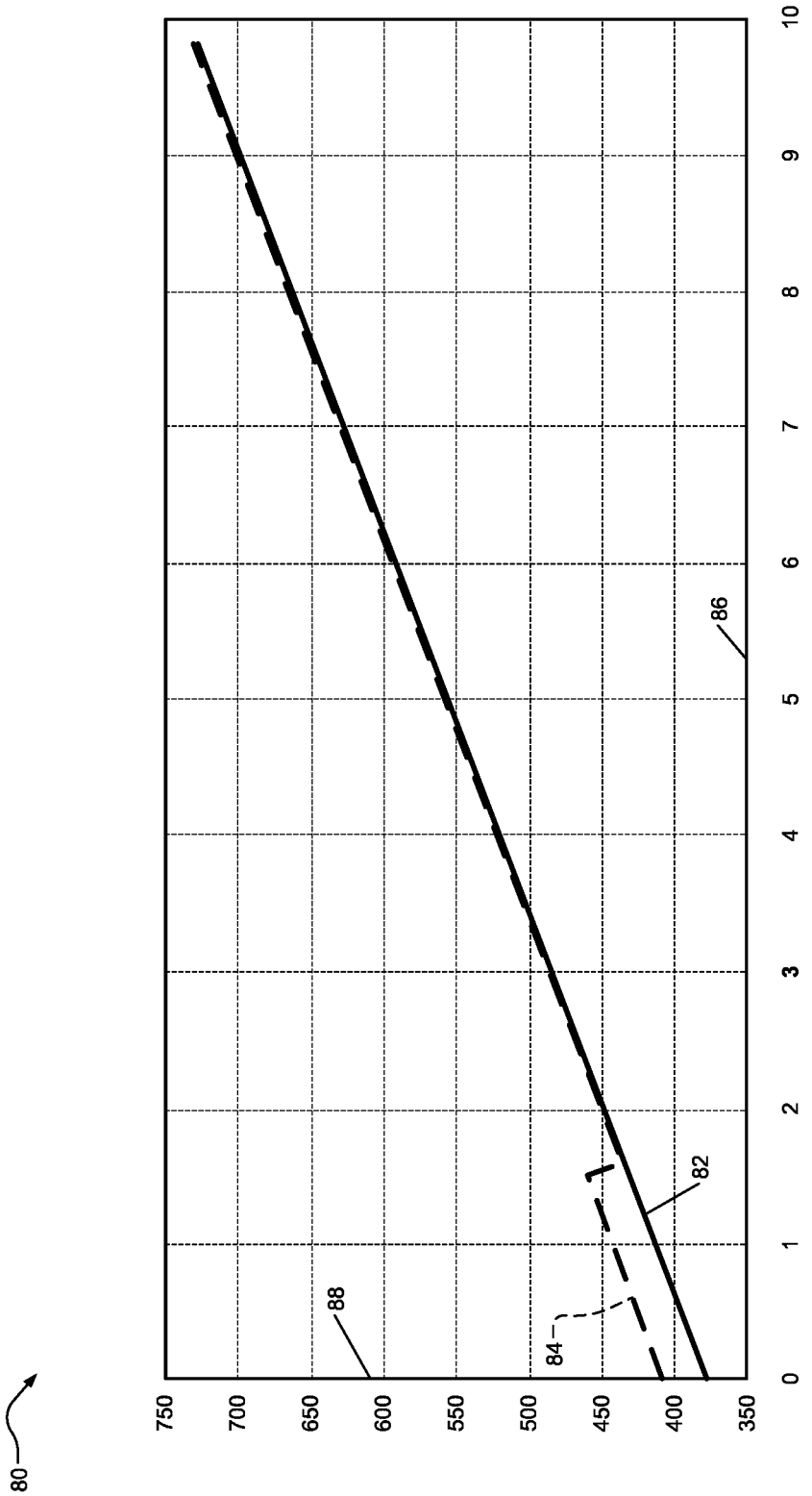


FIG. 4

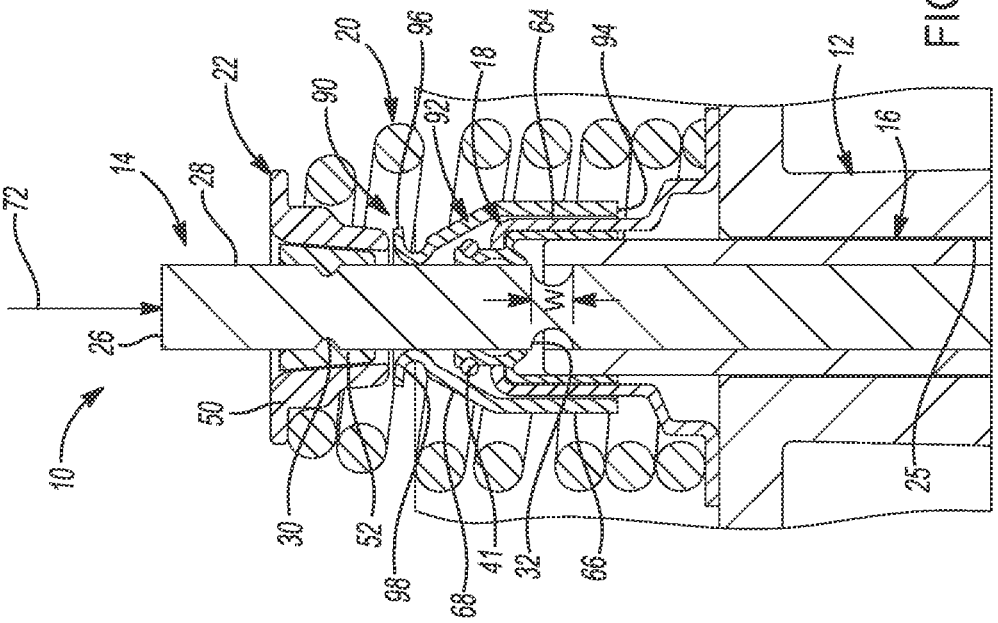

72
14
28
22
90
20
96
18
64
94
12
16
92
W
26
50
10
30
52
98
68
41
32
66
25

FIG. 6

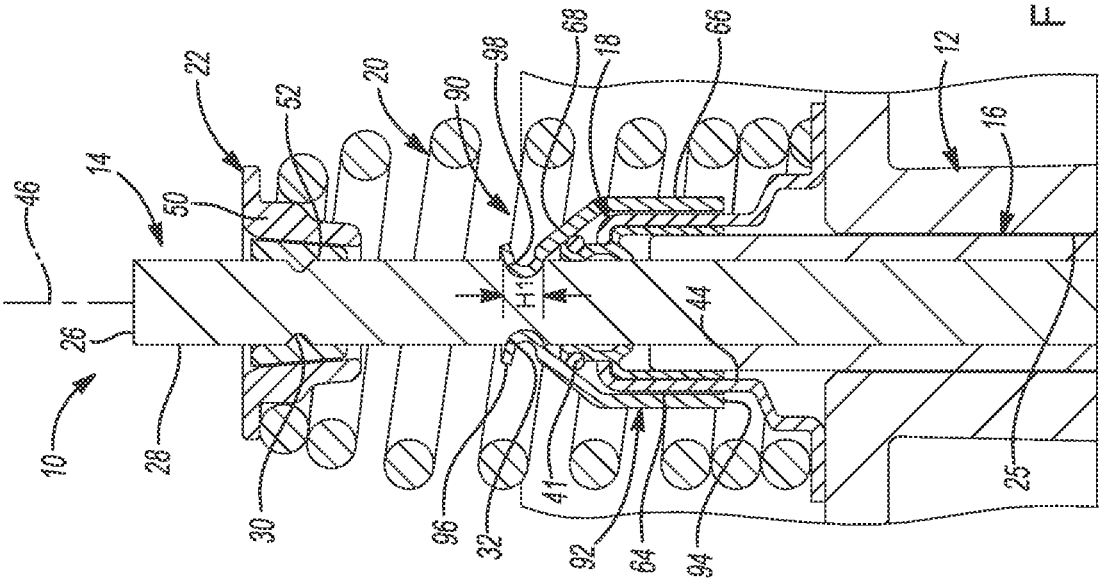

46
14
50
22
52
20
90
98
68
18
66
12
16
H
26
44
10
28
30
96
32
41
92
64
94
25

FIG. 5

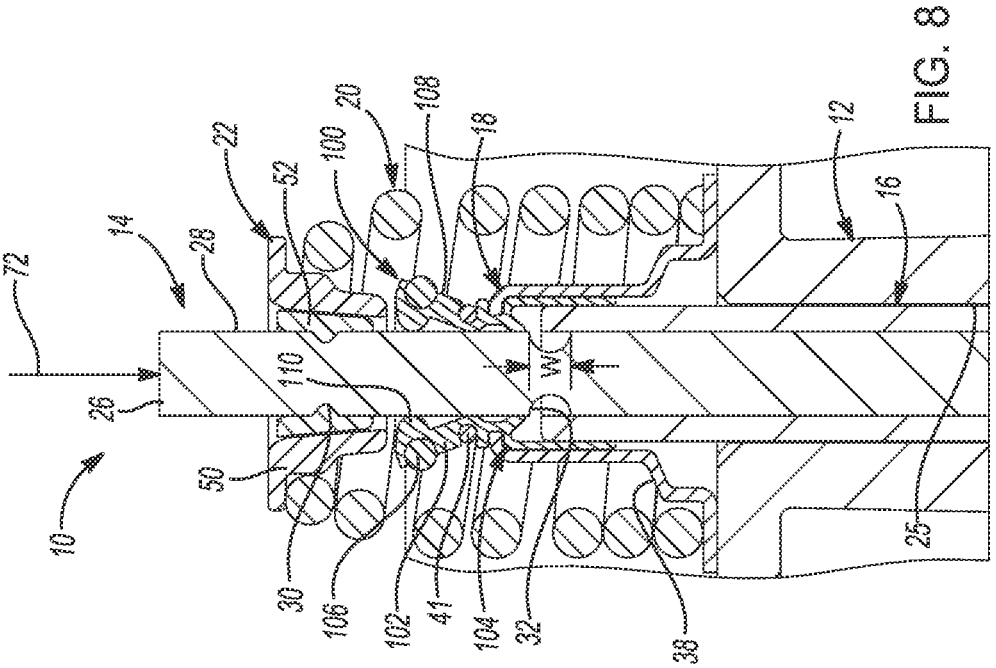

72
14
28
22
52
100
20
108
18
12
16
110
W1
26
50
10
30
106
102
41
104
32
38
25

FIG. 8

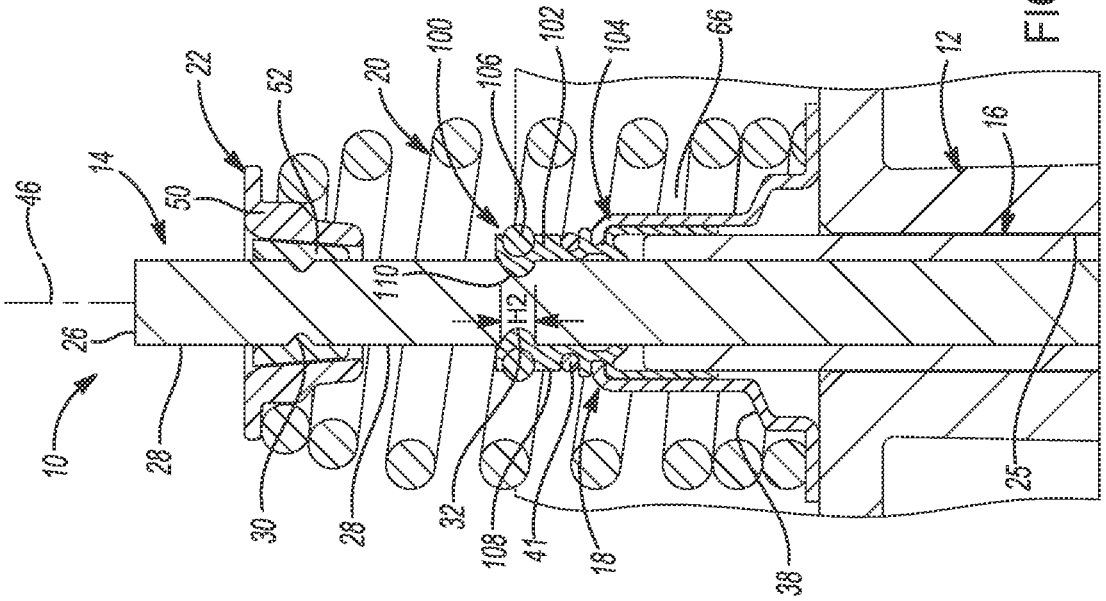

46
14
50
22
52
20
100
106
102
104
66
12
16
110
H2
26
10
28
30
28
32
108
41
18
38
25

FIG. 7

ENGINE VALVE ASSEMBLY INCLUDING DETENT MECHANISM CONFIGURED TO INCREASE FORCE BIASING VALVE TOWARD CLOSED POSITION WHEN VALVE IS AT OR NEAR CLOSED POSITION

INTRODUCTION

[0001] The information provided in this section is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0002] The present disclosure relates to engine valve assemblies including a detent mechanism configured to increase a force biasing a valve toward its closed position when the valve is at or near its closed position.

[0003] An intake or exhaust valve of an engine typically includes a valve body, a valve stem, a valve head, a valve guide, a valve spring, and a spring retainer. The valve body defines a hole through which intake air or exhaust gas flows. The valve stem is a rod, and the valve head is a disk attached to one end of the rod. The valve stem and the valve head are referred to collectively as a poppet valve. The valve head seats against a valve seat defined by the valve body and plugs the hole therein to prevent gas flow through the hole when the poppet valve is in its closed position.

[0004] The valve guide maintains the valve stem and head structure in alignment with the valve seat. The valve spring biases the poppet valve toward its closed position. The spring retainer is spaced apart from the valve body along the longitudinal axis of the valve stem. The valve spring is captured between the valve body and the spring retainer.

SUMMARY

[0005] A valve assembly for a cylinder of an engine is described herein. In one example, the valve assembly includes a valve body, a valve stem, a spring retainer, a valve spring and a detent mechanism. The valve body defines a bore therein. The valve stem extends through the bore in the valve body. The valve stem is adjustable between an open position and a closed position. The spring retainer is spaced apart from the valve body along a longitudinal axis of the valve stem and fixed relative to the valve body. The spring retainer defines a bore through which the valve stem extends. The valve spring is captured between the valve body and the spring retainer and is configured to apply a biasing force to the valve stem that biases the valve stem toward the closed position. The detent mechanism is configured to increase the biasing force applied to the valve stem when the valve stem is in the closed position or within a predetermined distance of the closed position.

[0006] In one aspect, the detent mechanism includes an annular groove formed in an outer radial surface of the valve stem and extending around a circumference thereof, and a cup spring fixed relative to the valve body and disposed about the circumference of the valve stem radially outward of the annular groove therein.

[0007] In one aspect, the valve assembly further includes ball detents captured between the valve stem and the cup spring. The ball detents engage the annular groove in the valve stem when the valve stem is in the closed position or within the predetermined distance of the closed position.

[0008] In one aspect, the valve assembly further includes a valve seal attached to an axial end surface of the valve body and engaging the outer radial surface of the valve stem. One end of the cup spring is attached to an outer radial surface of the valve seal and the other end of the cup spring captures the ball detents.

[0009] In one aspect, a width of the annular groove is greater than a diameter of the ball detents.

[0010] In one aspect, the annular groove has a ramped profile extending from a bottom surface of the annular groove to the outer radial surface of the valve stem. The ball detents engage the ramped profile as the valve stem is moved from the closed position toward the open position.

[0011] In one aspect, the cup spring forms an annular rib that engages the annular groove in the valve stem when the valve stem is in the closed position or within the predetermined distance of the closed position.

[0012] In one aspect, the valve assembly further includes a valve seal attached to an axial end surface of the valve body and engaging the outer radial surface of the valve stem. One end of the cup spring is attached to an outer radial surface of the valve seal and the other end of the cup spring forms the annular rib.

[0013] In one aspect, the cup spring includes a hollow cylindrical section attached to the outer radial surface of the valve seal and a hollow conical frustum section extending radially inward from the hollow cylindrical section to the annular rib formed by the cup spring. The annular rib projects radially inward from the hollow conical frustum section.

[0014] In one aspect, the detent mechanism includes an annular groove formed in an outer radial surface of the valve stem and extending around a circumference thereof, a valve seal attached to the valve body and engaging the outer radial surface of the valve stem, and a garter spring engaging an outer radial surface of the valve seal and extending around a circumference thereof. The garter spring biases the valve seal into engagement with the annular groove in the valve stem when the valve stem is in the closed position or within the predetermined distance of the closed position.

[0015] In one aspect, the valve seal includes a seal body and a seal lip. The seal body is attached to an axial end surface of the valve body and disposed about the circumference of the valve stem. The seal lip attached to an inner radial surface of the seal body projects radially inward therefrom and engages the outer radial surface of the valve stem. The garter spring engages the outer radial surface of the seal lip.

[0016] In one aspect, the valve assembly further includes a valve guide having a hollow cylindrical body including a first portion disposed radially between the valve stem and the valve body and a second portion disposed radially between the valve seal and the valve stem.

[0017] In one aspect, the predetermined distance is less than 25 percent of a peak lift of the valve stem.

[0018] In another example, the valve assembly includes a valve body, a valve stem, a spring retainer, a valve spring, a cup spring, and at least one detent. The valve body defines a bore therein. The valve stem extends through the bore in the valve body and has an outer radial surface with an annular groove formed therein. The valve stem is adjustable between an open position and a closed position. The spring

retainer is spaced apart from the valve body along a longitudinal axis of the valve stem and is fixed relative to the valve body. The spring retainer defines a bore through which the valve stem extends. The valve spring is captured between the valve body and the spring retainer and is configured to apply a biasing force to the valve stem that biases the valve stem toward the closed position. The cup spring is fixed relative to the valve body and disposed about a circumference of the valve stem radially outward of the annular groove therein. The at least one detent engages the annular groove in the valve stem when the valve stem is in the closed position, and thereby inhibits movement of the valve stem from the closed position toward the open position.

[0019] In one aspect, the at least one detent includes ball detents captured between the valve stem and the cup spring.

[0020] In one aspect, the cup spring includes a ring-shaped section that captures the ball detents.

[0021] In one aspect, the at least one detent includes an annular rib formed by the cup spring.

[0022] In one aspect, the annular groove has a ramped profile extending from a bottom surface of the annular groove to the outer radial surface of the valve stem, and the at least one detent engages the ramped profile as the valve stem is moved from the closed position toward the open position.

[0023] In another example, the valve assembly includes a valve body, a valve stem, a spring retainer, a valve spring, a valve seal, and a garter spring. The valve body defines a bore therein. The valve stem extends through the bore in the valve body. The valve stem has an outer radial surface with an annular groove formed therein. The valve stem is adjustable between an open position and a closed position. The spring retainer is spaced apart from the valve body along a longitudinal axis of the valve stem and fixed relative to the valve body. The spring retainer defines a bore through which the valve stem extends. The valve spring is captured between the valve body and the spring retainer and is configured to apply a biasing force to the valve stem that biases the valve stem toward the closed position. The valve seal is attached to the valve body and engages the outer radial surface of the valve stem. The garter spring engages an outer radial surface of the valve seal and extends around a circumference thereof. The garter spring biases the valve seal into engagement with the annular groove in the valve stem. The engagement between the valve seal and the annular groove inhibits movement of the valve stem from the closed position toward the open position.

[0024] In one aspect, the valve seal includes a seal body and a seal lip. The seal body is attached to an axial end surface of the valve body and disposed about a circumference of the valve stem. The seal lip is attached to an inner radial surface of the seal body, projects radially inward therefrom, and engages the outer radial surface of the valve stem. The garter spring engages the outer radial surface of the seal lip.

[0025] Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0027] FIG. **1** is a section view of a valve assembly including a valve stem shown in its closed position, a valve spring, and an example of a detent mechanism according to the present disclosure;

[0028] FIG. **2** is a section view of the valve assembly of FIG. **1** with the valve stem shown in its open position;

[0029] FIG. **3** is a section view of a portion of a variation of the valve assembly of FIG. **1** with the valve stem defining an annular groove having a ramped profile;

[0030] FIG. **4** is a graph illustrating a biasing force applied by the valve spring and the detent mechanism that urges the valve stem toward its closed position;

[0031] FIG. **5** is a section view of a valve assembly including a valve stem shown in its closed position and another example of a detent mechanism according to the present disclosure;

[0032] FIG. **6** is a section view of the valve assembly of FIG. **5** with the valve stem shown in its open position;

[0033] FIG. **7** is a section view of a valve assembly including a valve stem shown in its closed position and yet another example of a detent mechanism according to the present disclosure; and

[0034] FIG. **8** is a section view of the valve assembly of FIG. **7** with the valve stem shown in its open position.

[0035] In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

[0036] During compression release engine braking, exhaust valves of cylinders are opened just before the compression strokes of the cylinders end, which releases the compressed gas trapped in the cylinders and thereby slows a vehicle. This process yields high exhaust gas pressure, which can cause an exhaust valve to open independent of a valve actuator that controls the position of the exhaust valve. Engine braking by restricting exhaust gas flow and/or increasing boost pressure can also yield high exhaust gas pressure, and therefore can also cause an exhaust valve to open independent of its valve actuator. A poppet valve may open independent of its valve actuator if the biasing force of the valve spring is less than the difference between the force of the exhaust gas acting on the backside of the poppet valve and the force of compressed gas acting on the cylinder side of the poppet valve. While this issue may be addressed by increasing the rate of the valve spring, increasing the rate of the valve spring decreases engine efficiency.

[0037] A valve assembly according to the present disclosure includes a detent mechanism that addresses the above issue without decreasing engine efficiency. The detent mechanism increases the biasing force urging the poppet valve toward its closed position only when the poppet valve is at or near its closed position, which prevents the poppet valve from opening independent from its valve actuator even when the engine is operating at a high load and a high speed. Conversely, when the poppet valve is away from its closed position, the detent mechanism does not affect the force applied by the valve actuator to open the poppet valve.

[0038] In one example, the detent mechanism includes an annular groove in the valve stem, ball detents, and a cup

spring that biases the ball detents into engagement with the annular groove when the poppet valve is at or near its closed position. In another example, the detent mechanism includes the annular groove in the valve stem and the cup spring, and one end of the cup spring forms an annular rib that engages the annular groove when the poppet valve is at or near its closed position. In yet another example, the detent mechanism includes the annular groove in the valve stem, a valve seal, and a garter spring that compresses the valve seal into the annular groove when the poppet valve is at or near its closed position.

[0039] Referring now to FIGS. **1** and **2**, a valve assembly **10** may be an intake or exhaust valve of an engine. The valve assembly **10** includes a valve body **12**, a valve stem **14**, a valve guide **16**, a valve seal **18**, a valve spring **20**, a spring retainer **22**, and a detent mechanism **24**. The valve body **12** defines a bore **25** through which the valve stem **14** extends. The valve body **12** may be part of a cylinder head of the engine. The cylinder head may be placed on top of an engine block (not shown) that defines cylinders of the engine. The valve body **12** may be made from aluminum.

[0040] The valve stem **14** is adjustable between a closed position (FIG. **1**) and an open position (FIG. **2**). The valve stem **14** has a cylindrical body with an upper end **26**, a lower end (not shown) opposite of the upper end **26**, and an outer radial surface **28**. A valve head (not shown) is joined to the lower end of the valve stem **14**. The valve head may be disk shaped. When the valve stem **14** is in its closed position as shown in FIG. **1**, the valve head seats against a valve seat defined by the cylinder head to prevent gas flow into or out of one of the cylinders. When the valve stem **14** is in its open position as shown in FIG. **2**, the valve head seats against a valve seat defined by the cylinder head to prevent gas flow into or out of the one cylinder.

[0041] The outer radial surface **28** of the valve stem **14** has first and second annular grooves **30** and **32** formed therein and extending around the circumference thereof. The first annular groove **30** in the valve stem **14** receives a portion of the spring retainer **22**. The engagement between the spring retainer **22** and the first annular groove **30** in the valve stem **14** secures the spring retainer **22** to the valve stem **14**. The second annular groove **32** in the valve stem **14** receives a portion of the detent mechanism **24**.

[0042] The valve stem **14** translates through the valve guide **16** as the valve stem **14** actuates between its open and closed positions. The valve guide **16** maintains the valve stem **14** in alignment with the bore **25** in the valve body **12**. In addition, the valve guide **16** acts as a bushing by minimizing wear on the valve body **12** and the valve stem **14** as the valve stem **14** actuates between its open and closed positions. The valve stem **14** and the valve guide **16** may be made from steel.

[0043] The valve guide **16** has a hollow cylindrical body with a first portion **34** and a second portion **36**. The first portion **34** of the valve guide **16** is disposed in the bore **25** in the valve body **12** and radially between the valve stem **14** and the valve body **12**. The second portion **36** of the valve guide **16** is disposed outside of the bore **25** in the valve body **12** and radially between the valve seal **18** and the valve stem **14**. The valve guide **16** may be pressed into the bore **25** in the valve body **12**.

[0044] The valve seal **18** seals the interface between the valve body **12** and the valve stem **14**. The valve seal **18** includes a seal body **38**, a seal lip **40**, and a garter spring **41**. The seal body **38** is attached (e.g., welded) to an axial end surface **42** of the valve body **12** and is disposed about the circumference of the valve stem **14**. The seal body **38** is made from a rigid material such as steel. The seal lip **40** is attached to an inner radial surface **44** of the seal body **38** and projects radially inward therefrom. The seal lip **40** is made from a flexible material such as rubber and may be over molded to the seal body **38**. The garter spring **41** biases the seal lip **40** into engagement with the outer radial surface **28** of the valve stem **14**.

[0045] The valve spring **20** applies a biasing force to the valve stem **14** that biases the valve stem **14** toward its closed position. The valve spring **20** is captured between the valve body **12** (or the valve seal **18**) and the spring retainer **22**. The valve spring **20** is a coil spring made from a metal such as steel.

[0046] The spring retainer **22** retains the valve spring **20**. The spring retainer **22** is spaced apart from the valve body **12** along a longitudinal axis **46** of the valve stem **14** and is fixed relative to the valve body **12**. The spring retainer **22** defines a bore **48** through which the valve stem **14** extends.

[0047] The spring retainer **22** includes a retainer body **50** and a keeper **52**. The retainer body **50** is made from a rigid material such as steel. The keeper **52** is made from a flexible material such as rubber and may be over molded to the retainer body **50**. The keeper **52** may have a cylindrical shape in its relaxed state. When the spring retainer **22** is assembled to the valve stem **14**, the keeper **52** is compressed between the retainer body **50** and the valve stem **14**. In turn, the keeper **52** includes an annular protrusion **54** that engages the first annular groove **30** in the valve stem **14** and thereby secures the spring retainer **22** to the valve stem **14**.

[0048] The detent mechanism **24** increases the biasing force urging the valve stem **14** toward its closed position when the valve stem **14** is in its closed position or within a predetermined distance of its closed position. In one example, the predetermined distance is less than 25 percent of the peak lift of the valve stem **14** (and the valve head joined thereto). In another example, the predetermined distance is less than 2 millimeters (mm). The detent mechanism **24** includes the second annular groove **32** in the valve stem **14**, a cup spring **56**, and ball detents **58**.

[0049] The cup spring **56** is fixed relative to the valve body **12** and is disposed about the circumference of the valve stem **14** radially outward of the second annular groove **32** therein. The cup spring **56** has a first end **60** and a second end **62** opposite of the first end **60**. The first end **60** of the cup spring **56** is attached to an outer radial surface **64** of the valve seal **18**. The second end **62** of the cup spring **56** captures the ball detents **58** and applies a biasing force to the ball detents **58** that urges the ball detents **58** into engagement with the second annular groove **32** in the valve stem **14**. The cup spring **56** may be made from a metal such as steel.

[0050] The cup spring **56** includes a hollow cylindrical section **66**, a hollow conical frustum section **68**, and a ring-shaped section **70**. The hollow cylindrical section **66** extends along the longitudinal axis **46** of the valve stem **14** from the first end **60** of the cup spring **56** to the hollow conical frustum section **68**. The hollow conical frustum section **68** extends along the longitudinal axis **46** of the valve stem **14** from the hollow cylindrical section **66** to the ring-shaped section **70**. The ring-shaped section **70** extends along the longitudinal axis **46** of the valve stem **14** from the

hollow cylindrical section **66** to the second end **62** of the cup spring **56**. The ring-shaped section **70** captures the ball detents **58**.

[0051] The ball detents **58** engage the second annular groove **32** in the valve stem **14** when the valve stem **14** is in its closed position, and thereby inhibit movement of the valve stem **14** from its closed position toward its open position. Although only two ball detents **58** are shown, the detent mechanism **24** may include more than two ball detents **58**, and the ball detents **58** may be disposed about the entire circumference of the valve stem **14**. Each ball detent **58** has a spherical shape and may be made from a metal such as steel.

[0052] A valve actuator (not shown) moves the valve stem **14** in a downward direction **72** to adjust the valve stem **14** from its closed position (FIG. **1**) to its open position (FIG. **2**). In doing so, the valve actuator compresses the valve spring **20** and thereby overcomes the biasing force applied by the valve spring **20** urging the valve stem **14** toward its closed position. In addition, the valve actuator moves the ball detents **58** radially outward out of the second annular groove **32** in the valve stem **14** and thereby overcomes the biasing force applied by the cup spring **56** urging the ball detents **58** into engagement with the second annular groove **32**.

[0053] Once the ball detents **58** are out of the second annular groove **32** in the valve stem **14**, the detent mechanism **24** does not increase the biasing force urging the valve stem **14** toward its closed position. Thus, the detent mechanism **24** increases the biasing force urging the valve stem **14** toward its closed position only when the valve stem **14** is in its closed position or within the predetermined distance thereof. The predetermined distance may be equal to the amount that the valve stem **14** travels between its closed position and the position in which the ball detents **58** are initially removed from the second annular groove **32** in the valve stem **14**.

[0054] In the example shown in FIGS. **1** and **2**, the radius of the second annular groove **32** in valve stem **14** is equal to, or nearly equal to, the radius of each ball detent **58**. Thus, the ball detents **58** may not engage the second annular groove **32** in valve stem **14** when the valve stem **14** is in its closed position due to manufacturing tolerances. In the example shown in FIG. **3**, the second annular groove **32** in valve stem **14** has a different radius than each ball detent **58**. More specifically, the second annular groove **32** in valve stem **14** has a width W that is greater than a diameter D of each ball detent **58** to absorb manufacturing tolerances.

[0055] In addition, the second annular groove **32** in valve stem **14** has a ramped profile **74** extending in from a bottom surface **76** of the second annular groove **32** to the outer radial surface **28** of the valve stem **14**. The ball detents **58** engage the ramped profile **74** as the valve stem **14** is moved from its closed position toward its open position. Furthermore, the second annular groove **32** in valve stem **14** has a ramped profile **78** extending from the bottom surface **76** of the second annular groove **32** to the outer radial surface **28** of the valve stem **14** in an opposite direction than the ramped profile **74**.

[0056] At least a portion of the ramped profile **74** of the second annular groove **32** in the valve stem **14** is oriented at a first angle A**1** relative to the outer radial surface **28** of the valve stem **14**. Increasing the first angle A**1** of the ramped profile **74** causes the detent mechanism **24** to apply a greater biasing force urging the valve stem **14** toward its closed position while providing less ability to accommodate manufacturing tolerances. Decreasing the first angle A**1** of the ramped profile **74** has the opposite effects. In one example, the first angle A**1** of the ramped profile **74** is within a range between 35 degrees and 55 degrees (e.g., 45 degrees).

[0057] At least a portion of the ramped profile **78** of the second annular groove **32** in valve stem **14** is oriented at a second angle A**2** relative to the outer radial surface **28** of the valve stem **14**. Thus, the force required to move the ball detents **58** out of the second annular groove **32** in the downward direction **72** is greater than the force required to move the ball detents **58** out of the second annular groove **32** in the opposite, upward direction. This prevents the ball detents **58** from moving in the downward direction **72** past the second annular groove **32** in the valve stem **14** and damaging the valve seal **18**.

[0058] The ramped profiles **74**, **78** of the second annular groove **32** in the valve stem **14** and the bottom surface **76** of the second annular groove **32** form the entire profile of the second annular groove **32**. No section of the profile of the second annular groove **32** is parallel to the longitudinal axis **46** of the valve stem **14**. Thus, the bottom surface **76** of the second annular groove **32** is not flat. As a result, the detent mechanism **24** increases the biasing force urging the valve stem **14** toward its closed position throughout the entire engagement between the ball detents **58** and the second annular groove **32** in the valve stem **14**.

[0059] Referring now to FIG. **4**, a graph **80** illustrates example biasing forces **82**, **84** urging the valve stem **14** toward its closed position. The biasing force **82** represents the biasing force applied by the valve spring **20** by itself. The biasing force **84** represents the biasing force applied by the valve spring **20** and the detent mechanism **24**. The biasing forces **82**, **84** are plotted with respect to an x-axis **86** the represents valve lift in mm and a y-axis **88** that represents force in newtons (N).

[0060] At a valve lift of 0 mm, the biasing force **82** is approximately **380** N, and the biasing force **84** is approximately **410** N. Thus, the detent mechanism **24** increases the biasing force urging the valve stem **14** toward its closed position by approximately **30** N. As the valve stem **14** is moved from its closed position toward its open position, the detent mechanism **24** continues to increase this biasing force by approximately **30** N until the valve lift is approximately 1.5 mm. At that point, the detent mechanism **24** stops increasing the biasing force urging the valve stem **14** toward its closed position, and the biasing forces **82**, **84** are equal to one another.

[0061] Referring now to FIGS. **5** and **6**, the valve assembly **10** is shown with a detent mechanism **90** in place of the detent mechanism **24**. The detent mechanism **90** includes the second annular groove **32** in the valve stem **14** and a cup spring **92**. The cup spring **92** has a first end **94** and a second end **96** opposite of the first end **94**. The first end **94** of the cup spring **92** is attached to the outer radial surface **28** of the valve seal **18**. Like the cup spring **56**, the cup spring **92** includes the hollow cylindrical section **66** and the hollow conical frustum section **68**. In contrast to the detent mechanism **24**, the detent mechanism **90** does not include the ball detents **58**, and the cup spring **92** does not include the ring-shaped section **70** that captures the ball detents **58**.

Instead, the second end **96** of the cup spring **92** forms an annular rib **98** that engages the outer radial surface **28** of the valve stem **14**.

[0062] The hollow conical frustum section **68** of the cup spring **92** biases the annular rib **98** into engagement with the second annular groove **32** in the valve stem **14** when the valve stem **14** is in its closed position or within the predetermined distance thereof. The engagement between the annular rib **98** and the second annular groove **32** inhibits movement of the valve stem **14** from its closed position toward its open position. The cup spring **92** may be made from a metal such as steel. In the example shown in FIGS. **5** and **6**, the second annular groove **32** in the valve stem **14** has a hemispherical profile with a radius that is approximately equal to the radius of the annular rib **98**. In other examples, the second annular groove **32** in the valve stem **14** may have a ramped profile as shown in the example of FIG. **3**, and the width W of the second annular groove **32** may be greater than a height H**1** of the annular rib **98**.

[0063] Referring now to FIGS. **7** and **8**, the valve assembly **10** is shown with a detent mechanism **100** in place of the detent mechanism **24**. The detent mechanism **100** includes the second annular groove **32** in the valve stem **14**, an upper portion **102** of a seal lip **104**, and a garter spring **106**. Like the seal lip **40**, the seal lip **104** is attached to the inner radial surface **44** of the seal body **38** and projects radially inward therefrom, the seal lip **104** is made from a flexible material, such as rubber, and the seal lip **104** may be over molded to the seal body **38**. In contrast to the seal lip **40**, the seal lip **104** includes the upper portion **102**, which projects in the upward direction from the portion of the seal lip **104** that corresponds to the seal lip **40**.

[0064] The garter spring **106** engages an outer radial surface **108** of the seal lip **104** and extends around the circumference thereof. The garter spring **106** biases the seal lip **104** into engagement with the second annular groove **32** in the valve stem **14** when the valve stem **14** is in its closed portion or within the predetermined distance thereof. The garter spring **106** may be made from steel. In various implementations, the garter springs **41**, **106** may be replaced with a single garter spring.

[0065] The upper portion **102** of the seal lip **104** may have a cylindrical shape in its relaxed state. When the garter spring **106** engages the outer radial surface **108** of the seal lip **104**, the garter spring **106** compresses the seal lip **104** radially inward and thereby forms an annular protrusion **110** in the upper portion **102** of the seal lip **104**. The annular protrusion **110** on the seal lip **104** projects radially inward from the remainder of the upper portion **102** of the seal lip **104**. The annular protrusion **110** on the seal lip **104** engages the second annular groove **32** in the valve stem **14** when the valve stem **14** is in its closed position, and thereby inhibits movement of the valve stem **14** from its closed position toward its open position. In the example shown in FIGS. **7** and **8**, the second annular groove **32** in the valve stem **14** has a hemispherical profile with a radius that is approximately equal to the radius of the annular protrusion **110**. In other examples, the second annular groove **32** in the valve stem **14** may have a ramped profile as shown in the example of FIG. **3**, and the width W of the second annular groove **32** may be greater than a height H**2** of the annular protrusion **110**.

[0066] The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure. Further, although each of the embodiments is described above as having certain features, any one or more of those features described with respect to any embodiment of the disclosure can be implemented in and/or combined with features of any of the other embodiments, even if that combination is not explicitly described. In other words, the described embodiments are not mutually exclusive, and permutations of one or more embodiments with one another remain within the scope of this disclosure.

[0067] Spatial and functional relationships between elements (for example, between modules, circuit elements, semiconductor layers, etc.) are described using various terms, including "connected," "engaged," "coupled," "adjacent," "next to," "on top of," "above," "below," and "disposed." Unless explicitly described as being "direct," when a relationship between first and second elements is described in the above disclosure, that relationship can be a direct relationship where no other intervening elements are present between the first and second elements, but can also be an indirect relationship where one or more intervening elements are present (either spatially or functionally) between the first and second elements.

[0068] Spatially relative terms, such as "inner," "outer," "beneath," "below," "lower," "above," "upper," and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0069] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as "first," "second," and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

[0070] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using

a non-exclusive logical OR, and should not be construed to mean "at least one of A, at least one of B, and at least one of C."

What is claimed is:

1. A valve assembly for a cylinder of an engine, the valve assembly comprising:

a valve body defining a bore therein;

a valve stem extending through the bore in the valve body, wherein the valve stem is adjustable between an open position and a closed position;

a spring retainer spaced apart from the valve body along a longitudinal axis of the valve stem and fixed relative to the valve body, the spring retainer defining a bore through which the valve stem extends;

a valve spring captured between the valve body and the spring retainer and configured to apply a biasing force to the valve stem that biases the valve stem toward the closed position; and

a detent mechanism configured to increase the biasing force applied to the valve stem when the valve stem is in the closed position or within a predetermined distance of the closed position.

2. The valve assembly of claim **1** wherein the detent mechanism includes:

an annular groove formed in an outer radial surface of the valve stem and extending around a circumference thereof; and

a cup spring fixed relative to the valve body and disposed about the circumference of the valve stem radially outward of the annular groove therein.

3. The valve assembly of claim **2** further comprising ball detents captured between the valve stem and the cup spring, wherein the ball detents engage the annular groove in the valve stem when the valve stem is in the closed position or within the predetermined distance of the closed position.

4. The valve assembly of claim **3** further comprising a valve seal attached to an axial end surface of the valve body and engaging the outer radial surface of the valve stem, wherein one end of the cup spring is attached to an outer radial surface of the valve seal and the other end of the cup spring captures the ball detents.

5. The valve assembly of claim **3** wherein a width of the annular groove is greater than a diameter of the ball detents.

6. The valve assembly of claim **3** wherein the annular groove has a ramped profile extending from a bottom surface of the annular groove to the outer radial surface of the valve stem, the ball detents engaging the ramped profile as the valve stem is moved from the closed position toward the open position.

7. The valve assembly of claim **3** wherein the cup spring forms an annular rib that engages the annular groove in the valve stem when the valve stem is in the closed position or within the predetermined distance of the closed position.

8. The valve assembly of claim **7** further comprising a valve seal attached to an axial end surface of the valve body and engaging the outer radial surface of the valve stem, wherein one end of the cup spring is attached to an outer radial surface of the valve seal and the other end of the cup spring forms the annular rib.

9. The valve assembly of claim **8** wherein the cup spring includes a hollow cylindrical section attached to the outer radial surface of the valve seal and a hollow conical frustum section extending radially inward from the hollow cylindrical section to the annular rib formed by the cup spring, the annular rib projecting radially inward from the hollow conical frustum section.

10. The valve assembly of claim **1** wherein the detent mechanism includes:

an annular groove formed in an outer radial surface of the valve stem and extending around a circumference thereof;

a valve seal attached to the valve body and engaging the outer radial surface of the valve stem; and

a garter spring engaging an outer radial surface of the valve seal and extending around a circumference thereof, the garter spring biasing the valve seal into engagement with the annular groove in the valve stem when the valve stem is in the closed position or within the predetermined distance of the closed position.

11. The valve assembly of claim **10** wherein the valve seal includes:

a seal body attached to an axial end surface of the valve body and disposed about the circumference of the valve stem; and

a seal lip attached to an inner radial surface of the seal body, projecting radially inward therefrom, and engaging the outer radial surface of the valve stem, wherein the garter spring engages the outer radial surface of the seal lip.

12. The valve assembly of claim **10** further comprising a valve guide having a hollow cylindrical body including a first portion disposed radially between the valve stem and the valve body and a second portion disposed radially between the valve seal and the valve stem.

13. The valve assembly of claim **1** wherein the predetermined distance is less than 25 percent of a peak lift of the valve stem.

14. A valve assembly for a cylinder of an engine, the valve assembly comprising:

a valve body defining a bore therein;

a valve stem extending through the bore in the valve body, the valve stem having an outer radial surface with an annular groove formed therein, wherein the valve stem is adjustable between an open position and a closed position;

a spring retainer spaced apart from the valve body along a longitudinal axis of the valve stem and fixed relative to the valve body, the spring retainer defining a bore through which the valve stem extends;

a valve spring captured between the valve body and the spring retainer and configured to apply a biasing force to the valve stem that biases the valve stem toward the closed position;

a cup spring fixed relative to the valve body and disposed about a circumference of the valve stem radially outward of the annular groove therein; and

at least one detent that engages the annular groove in the valve stem when the valve stem is in the closed position, and thereby inhibits movement of the valve stem from the closed position toward the open position.

15. The valve assembly of claim **14** wherein the at least one detent includes ball detents captured between the valve stem and the cup spring.

16. The valve assembly of claim **15** wherein the cup spring includes a ring-shaped section that captures the ball detents.

17. The valve assembly of claim **14** wherein the at least one detent includes an annular rib formed by the cup spring.

18. The valve assembly of claim **14** wherein the annular groove has a ramped profile extending from a bottom surface of the annular groove to the outer radial surface of the valve stem, the at least one detent engaging the ramped profile as the valve stem is moved from the closed position toward the open position.

19. A valve assembly for a cylinder of an engine, the valve assembly comprising:

a valve body defining a bore therein;

a valve stem extending through the bore in the valve body, the valve stem having an outer radial surface with an annular groove formed therein, wherein the valve stem is adjustable between an open position and a closed position;

a spring retainer spaced apart from the valve body along a longitudinal axis of the valve stem and fixed relative to the valve body, the spring retainer defining a bore through which the valve stem extends;

a valve spring captured between the valve body and the spring retainer and configured to apply a biasing force to the valve stem that biases the valve stem toward the closed position;

a valve seal attached to the valve body and engaging the outer radial surface of the valve stem; and

a garter spring engaging an outer radial surface of the valve seal and extending around a circumference thereof, the garter spring biasing the valve seal into engagement with the annular groove in the valve stem, the engagement between the valve seal and the annular groove inhibiting movement of the valve stem from the closed position toward the open position.

20. The valve assembly of claim **19** wherein the valve seal includes:

a seal body attached to an axial end surface of the valve body and disposed about a circumference of the valve stem; and

a seal lip attached to an inner radial surface of the seal body, projecting radially inward therefrom, and engaging the outer radial surface of the valve stem, wherein the garter spring engages the outer radial surface of the seal lip.

* * * * *