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HYDROGEN ENGINE

Abstract

A hydrogen engine using fuel gas containing hydrogen, including: a cylinder; a piston movable within the cylinder; a cylinder head forming a combustion chamber with the piston, and including an intake port connected to the combustion chamber and a fuel supply port connected to the combustion chamber; an intake valve for opening and closing the intake port; a fuel supply valve for opening and closing the fuel supply port; and a valve train commonly provided for the intake valve and the fuel supply valve, and configured to open and close the intake valve and the fuel supply valve in conjunction with each other. The hydrogen engine is configured such that a valve opening timing of the fuel supply valve is more retarded than a valve opening timing of the intake valve.

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure relates to a hydrogen engine.

[0002] This application claims the priority of Japanese Patent Application No. 2022-071572 filed on Apr. 25, 2022, the content of which is incorporated herein by reference.

BACKGROUND

[0003] Patent Document 1 discloses a hydrogen engine that uses hydrogen fuel. In this hydrogen engine, an injector for injecting the hydrogen fuel into an intake port is provided, and intake air flowing in the intake port and the hydrogen fuel injected from the injector are mixed and supplied to a combustion chamber.

CITATION LIST

Patent Literature

[0004] Patent Document 1: JP2016-118109A

SUMMARY

Technical Problem

[0005] Since hydrogen has a wide combustible range and a fast combustion speed, when the hydrogen fuel is injected into the intake port as described in Patent Document 1, backfire is likely to occur in which a flame travels back to the intake port, and there is a risk of damage to an intake path. In order to suppress such backfire, a method for providing a fuel supply port separately from the intake port and supplying fuel gas to the combustion chamber without via the intake port is conceivable. However, since there is a period of overlap between an intake valve opening period and an exhaust valve opening period, if a part of the fuel gas supplied from the fuel supply port to the combustion chamber is discharged from the exhaust port without being burned, engine efficiency will be decreased.

[0006] In view of the above, an object of at least one embodiment of the present disclosure is to provide a hydrogen engine that can suppress the occurrence of the backfire and can achieve high engine efficiency.

Solution to Problem

[0007] In order to achieve the above-described object, a hydrogen engine according to at least one embodiment of the present disclosure is a hydrogen engine using fuel gas containing hydrogen, including: a cylinder; a piston movable within the cylinder; a cylinder head forming a combustion chamber with the piston, and including an intake port connected to the combustion chamber and a fuel supply port connected to the combustion chamber; an intake valve for opening and closing the intake port; a fuel supply valve for opening and closing the fuel supply port; and a valve train commonly provided for the intake valve and the fuel supply valve, and configured to open and close the intake valve and the fuel supply valve in conjunction with each other. The hydrogen engine is configured such that a valve opening timing of the fuel supply valve is more retarded than

a valve opening timing of the intake valve.
[0008] In order to achieve the above-described object, a hydrogen engine according to at least one embodiment of the present disclosure is a hydrogen engine using fuel gas containing hydrogen, including: a cylinder; a piston movable within the cylinder; a cylinder head forming a combustion chamber with the piston, and including an intake port connected to the combustion chamber, a fuel supply port connected to the combustion chamber, and an exhaust port connected to the combustion chamber; an intake valve for opening and closing the intake port; a fuel supply valve for opening and closing the fuel supply port; a valve train commonly provided for the intake valve and the fuel supply valve, and configured to open and close the intake valve and the fuel supply valve in conjunction with each other; and a cover portion configured to cover at least a part of an outlet portion of the fuel supply port on a side of the exhaust port in at least a part of a valve opening period of the fuel supply valve.
[0009] In order to achieve the above-described object, a hydrogen engine according to at least one embodiment of the present disclosure is a hydrogen engine using fuel gas containing hydrogen, including: a cylinder; a piston movable within the cylinder; a cylinder head forming a combustion chamber with the piston, and including an intake port connected to the combustion chamber, a fuel supply port connected to the combustion chamber, and an exhaust port connected to the combustion chamber; an intake valve for opening and closing the intake port; a fuel supply valve for opening and closing the fuel supply port; and a valve train commonly provided for the intake valve and the fuel supply valve, and configured to open and close the intake valve and the fuel supply valve in conjunction with each other. A lower surface of the cylinder head is formed along a plane. A lower surface of the fuel supply valve is located upstream of a flow of the fuel gas in an axial direction of the fuel supply valve relative to the lower surface of the cylinder head, in a state in which the fuel supply valve abuts against a valve seat surface disposed in the fuel supply port.
ADVANTAGEOUS EFFECTS
[0010] According to at least one embodiment of the present disclosure, a hydrogen engine is provided which can suppress the occurrence of backfire and can achieve high engine efficiency.

Description

BRIEF DESCRIPTION OF DRAWINGS
[0011] FIG. **1** is a schematic cross-sectional view of a hydrogen engine **2** according to an embodiment.
[0012] FIG. **2** is a side view showing an example of a detailed configuration of a valve train **18**.
[0013] FIG. **3** is an enlarged view showing an example of the configuration in the vicinity of another end portion **44***b* of an intake rocker arm **44** shown in FIGS. **1** and **2**.
[0014] FIG. **4** is a chart showing an example of changes in respective effective opening areas of an intake valve **10**, an exhaust valve **14**, and a fuel supply valve **15** in one combustion cycle of the hydrogen engine **2**.
[0015] FIG. **5**A is a view for describing an example of a detailed configuration of the fuel supply valve **15** shown in FIGS. **1** and **2**, and shows a state in which a valve body portion **36** of the fuel supply valve **15** abuts against a valve seat surface **54** of a fuel supply port **26** and the fuel supply port **26** is closed.
[0016] FIG. **5**B is a view for describing an example of the detailed configuration of the fuel supply valve **15** shown in FIGS. **1** and **2**, and shows a state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is open.
[0017] FIG. **5**C is a view for describing an example of the detailed configuration of the fuel supply valve **15** shown in FIGS. **1** and **2**, and shows a state in which the valve body portion **36** of the fuel

supply valve **15** is separated from the valve seat surface **54** and the fuel supply port **26** is closed by a collar portion **50** of the fuel supply valve **15** (a state between the state shown in FIG. **5**A and the state shown in FIG. **5**B).

[0018] FIG. **6** is a graph showing a relationship between a crank angle of the hydrogen engine **2** and a lift amount of each of the exhaust valve **14** and the fuel supply valve **15**.

[0019] FIG. **7**A is a view for describing an example of a detailed configuration of a cylinder head **8** shown in FIGS. **1** and **2**, and shows the state in which the valve body portion **36** of the fuel supply valve **15** abuts against the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is closed.

[0020] FIG. **7**B is a view for describing an example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**, and shows the state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is open.

[0021] FIG. **7**C is a view for describing an example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**, and shows a state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** and the valve body portion **36** of the fuel supply valve **15** is in contact with an inner peripheral surface of a valve seat member **56** (a state between the state shown in FIG. **7**A and the state shown in FIG. **7**B).

[0022] FIG. **8**A is a view for describing an example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**, and shows the state in which the valve body portion **36** of the fuel supply valve **15** abuts against the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is closed.

[0023] FIG. **8**B is a view for describing an example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**, and shows the state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is open.

[0024] FIG. **8**C is a view for describing an example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**, and shows the state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is open (a state between the state shown in FIG. **8**A and the state shown in FIG. **8**B).

[0025] FIG. **9**A is a view for describing an example of the detailed configuration of the fuel supply valve **15** shown in FIGS. **1** and **2**, and shows the state in which the valve body portion **36** of the fuel supply valve **15** abuts against the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is closed.

[0026] FIG. **9**B is a view for describing an example of the detailed configuration of the fuel supply valve **15** shown in FIGS. **1** and **2**, and shows the state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is open.

[0027] FIG. **9**C is a view for describing an example of the detailed configuration of the fuel supply valve **15** shown in FIGS. **1** and **2**, and shows a state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** and at least a part of an outlet portion **70** of the fuel supply port **26** on an exhaust port **24** side is covered by the collar portion **72** (cover portion) of the fuel supply valve **15** (a state between the state shown in FIG. **9**A and the state shown in FIG. **9**B).

[0028] FIG. **10**A is a view for describing an example of a range in which the collar portion **72** is disposed.

[0029] FIG. **10**B is a view for describing another example of the range in which the collar portion **72** is disposed.

[0030] FIG. **11** is a view for describing still another example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**.

[0031] FIG. **12**A is a view for describing an example of a range in which a protruding portion **76** of a mask plate **74** is disposed.
[0032] FIG. **12**B is a view for describing another example of the range in which the protruding portion **76** of the mask plate **74** is disposed.
[0033] FIG. **13** is a view for describing yet another example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**.
[0034] FIG. **14**A is a view for describing an example of a range in which a protruding portion **77** of the valve seat member **56** is disposed.
[0035] FIG. **14**B is a view for describing another example of the range in which the protruding portion **77** of the valve seat member **56** is disposed.

DETAILED DESCRIPTION

[0036] Some embodiments of the present disclosure will be described below with reference to the accompanying drawings. It is intended, however, that unless particularly identified, dimensions, materials, shapes, relative positions and the like of components described or shown in the drawings as the embodiments shall be interpreted as illustrative only and not intended to limit the scope of the present invention.
[0037] For instance, an expression of relative or absolute arrangement such as “in a direction”, “along a direction”, “parallel”, “orthogonal”, “centered”, “concentric” and “coaxial” shall not be construed as indicating only the arrangement in a strict literal sense, but also includes a state where the arrangement is relatively displaced by a tolerance, or by an angle or a distance whereby it is possible to achieve the same function.
[0038] For instance, an expression of an equal state such as “same”, “equal”, and “uniform” shall not be construed as indicating only the state in which the feature is strictly equal, but also includes a state in which there is a tolerance or a difference that can still achieve the same function.
[0039] Further, for instance, an expression of a shape such as a rectangular shape or a tubular shape shall not be construed as only the geometrically strict shape, but also includes a shape with unevenness or chamfered corners within the range in which the same effect can be achieved.
[0040] On the other hand, the expressions “comprising”, “including”, “having”, “containing”, and “constituting” one constituent component are not exclusive expressions that exclude the presence of other constituent components.

Hydrogen Engine

[0041] FIG. **1** is a schematic cross-sectional view of a hydrogen engine **2** according to an embodiment. Hereinafter, the hydrogen engine **2** will be described taking as an example a four-stroke engine that uses fuel gas containing hydrogen. The hydrogen concentration of the fuel gas used by the hydrogen engine **2** may be, for example, at least 50%, at least 75%, or at least 99%.
[0042] As shown in FIG. **1**, the hydrogen engine **2** includes a cylinder **4**, a piston **6**, a cylinder head **8**, an intake valve **10**, a valve spring **12**, an exhaust valve **14**, a fuel supply valve **15**, a valve spring **16**, and a valve train **18**.
[0043] The piston **6** is configured to be movable within the cylinder **4**. The piston **6** reciprocates within the cylinder **4** such that an outer peripheral surface of the piston **6** slides on an inner peripheral surface of the cylinder **4**, and a crankshaft (not shown) connected to the piston **6** rotates in conjunction with the reciprocation of the piston **6**.
[0044] The cylinder head **8** forms a combustion chamber **20** with the piston **6**. The cylinder head **8** includes an intake port **22** connected to the combustion chamber **20**, an exhaust port **24** connected to the combustion chamber **20**, and a fuel supply port **26** connected to the combustion chamber **20**. In the illustrated example, a lower surface **9** of the cylinder head **8** is formed along a plane orthogonal to the axial direction of the piston **6**.
[0045] The intake valve **10** is configured to open and close the intake port **22**. The intake valve **10** includes a valve stem **28**, a valve body portion **30** disposed on one end side of the valve stem **28**, and a force receiving portion **32** disposed on another end side of the valve stem **28**. In the

illustrated example, the valve stem **28** extends in an up-down direction, the valve body portion **30** is disposed at a lower end of the valve stem **28**, and the force receiving portion **32** is disposed at an upper end of the valve stem **28**. Further, in the illustrated example, the valve body portion **30** is formed in a truncated cone shape such that an outer diameter of the valve body portion **30** decreases toward an upstream side of an intake air flow, and an inclined surface (an inclined surface inclined with respect to the axial direction of the intake valve **10**) of the truncated cone shape is disposed to be abuttable against a valve seat surface of the intake port **22** in the axial direction of the intake valve **10** (the axial direction of the valve stem **28**). Furthermore, in the illustrated example, the force receiving portion **32** is formed in a plate shape along the plane orthogonal to the axial direction of the intake valve **10**.

[0046] The valve spring **12** is interposed in a compressed state between an upper surface of the cylinder head **8** and a lower surface of the force receiving portion **32**, and biases the force receiving portion **32** upward to bias the intake valve **10** in a closing direction.

[0047] The exhaust valve **14** is configured to open and close the exhaust port **24**. The exhaust valve **14** has a structure similar to that of the intake valve **10**, and a valve spring (not shown) biases the exhaust valve **14** in a closing direction.

[0048] The fuel supply valve **15** is configured to open and close the fuel supply port **26**. The fuel supply valve **15** includes a valve stem **34**, a valve body portion **36** disposed on one end side of the valve stem **34**, and a force receiving portion **38** disposed on another end side of the valve stem **34**. In the illustrated example, the valve stem **34** extends in the up-down direction, the valve body portion **36** is disposed at a lower end of the valve stem **34**, and the force receiving portion **38** is disposed at an upper end of the valve stem **34**. Further, in the illustrated example, the valve body portion **36** is formed in a truncated cone shape such that an outer diameter of the valve body portion **36** decreases toward an upstream side of a fuel gas flow, and an inclined surface **53** (an inclined surface inclined with respect to the axial direction of the fuel supply valve **15**) of the truncated cone shape is disposed to be abuttable against a valve seat surface **54** of the fuel supply port **26** in the axial direction of the fuel supply valve **15** (the axial direction of the valve stem **34**). Furthermore, in the illustrated example, the force receiving portion **38** is formed in a plate shape along a plane orthogonal to the axial direction of the fuel supply valve **15**.

[0049] The valve spring **16** is interposed in a compressed state between the upper surface of the cylinder head **8** and a lower surface of the force receiving portion **38**, and biases the force receiving portion **38** upward to bias the fuel supply valve **15** in a closing direction.

[0050] The valve train **18** is commonly provided for the intake valve **10** and the fuel supply valve **15**, and is configured to open and close the intake valve **10** and the fuel supply valve **15** in conjunction with each other. An example of the detailed configuration of the valve train **18** will be described later.

[0051] In the above-described hydrogen engine **2**, the fuel gas supplied from the fuel supply port **26** and air supplied from the intake port **22** are mixed in the combustion chamber **20** and ignited by an ignition device (not shown) to burn a combustion gas. In the above configuration, the fuel supply port **26** is disposed separately from the intake port **22**, and the fuel gas containing hydrogen is supplied to the combustion chamber **20** from the fuel supply port **26** without via the intake port **22**. Therefore, it is possible to suppress the occurrence of backfire in which a flame travels back to the intake port **22**.

Valve Train

[0052] FIG. **2** is a side view showing an example of the detailed configuration of the valve train **18**.

[0053] As shown in FIG. **2**, the valve train **18** includes an intake camshaft **40**, an intake cam **41**, a push rod **42**, an intake rocker arm **44**, a rocker arm shaft **46**, and a fuel supply valve arm **48**.

[0054] The intake cam **41** is formed integrally with the intake camshaft **40** in the intake camshaft **40**. The intake camshaft **40** rotates together with the intake cam **41** in conjunction with a rotation of a crankshaft (not shown) of the hydrogen engine **2**. A lower end portion of the push rod **42** abuts against an outer peripheral surface (cam surface) of the intake cam **41**, and as the intake cam **41** rotates, a distance r between the push rod **42** and a rotational axis C**1** of the intake cam **41** changes, causing the push rod **42** to reciprocate in the axial direction of the push rod **42**.

[0055] The intake rocker arm **44** is supported by the rocker arm shaft **46** so as to be rotatable around a central axis C**2** of the rocker arm shaft **46** (a rotational axis of the intake rocker arm **44**). A lower surface in one end portion **44***a* of the intake rocker arm **44** abuts against an upper end portion of the push rod **42**. As the push rod **42** reciprocates in the axial direction of the push rod **42** in response to the rotation of the intake cam **41**, the upper end portion of the push rod **42** presses the lower surface in the one end portion **44***a* of the intake rocker arm **44**, causing the intake rocker arm **44** to rotate (swing) around the above-described rotational axis C**2**.

[0056] A lower surface in another end portion **44***b* of the intake rocker arm **44** can press the intake valve **10** when the intake rocker arm **44** rotates. The rotation of the intake rocker arm **44** causes the lower surface in the another end portion **44***b* of the intake rocker arm **44** to push the intake valve **10** down against a biasing force of the valve spring **12** (see FIG. **1**), causing the intake valve **10** to move in an open direction. Further, the rotation of the intake rocker arm **44** displaces the another end portion **44***b* of the intake rocker arm **44** in a direction of the biasing force of the valve spring **12**, causing the intake valve **10** to move in the closing direction.

[0057] The fuel supply valve arm **48** is connected to an another end portion **44***b* side of the intake rocker arm **44**, and rotates around the rotational axis C**2** together with the intake rocker arm **44**. Since the fuel supply valve arm **48** rotates around the rotational axis C**2**, a tip portion **48***a* of the fuel supply valve arm **48** can press the fuel supply valve **15**.

[0058] The rotation of the intake rocker arm **44** causes the tip portion **48***a* of the fuel supply valve arm **48** to push the fuel supply valve **15** down against a biasing force of the valve spring **16** (see FIG. **1**), causing the fuel supply valve **15** to move in the open direction. Further, the rotation of the intake rocker arm **44** displaces the tip portion **48***a* of the fuel supply valve arm **48** in a direction of the biasing force of the valve spring **16**, causing the fuel supply valve **15** to move in the closing direction.

Fuel Supply Valve and its Surrounding Configuration

[0059] FIG. **3** is an enlarged view showing an example of the configuration in the vicinity of the another end portion **44***b* of the intake rocker arm **44** shown in FIGS. **1** and **2**. FIG. **4** is a chart showing an example of changes in respective effective opening areas of the intake valve **10**, the exhaust valve **14**, and the fuel supply valve **15** in one combustion cycle of the hydrogen engine **2**.

[0060] In some embodiments, for example as shown in FIG. **3**, where g1 is a distance between the fuel supply valve arm **48** and the fuel supply valve **15** and g2 is a distance between the intake rocker arm **44** and the intake valve **10**, a maximum value g1max of the distance g1in the one combustion cycle of the hydrogen engine **2** may be greater than a maximum value g2max of the distance g2 in the one combustion cycle of the hydrogen engine **2**. For example, in the configuration shown in FIG. **2**, when the distance r between the rotation center C**1** of the intake cam **41** and the push rod **42** is at its minimum value during one rotation of the intake cam **41**, the distance g1 between the fuel supply valve arm **48** and the fuel supply valve **15** and the distance g2 between the intake rocker arm **44** and the intake valve **10** are at the maximum value g1max and the maximum value g2max, respectively (that is, the intake valve **10** and the fuel supply valve **15** are at their valve closing positions, respectively), and the maximum value g1max is greater than the maximum value g2max.

[0061] As a result, as shown in FIG. **4**, in an intake stroke of the hydrogen engine **2**, a valve opening timing FO of the fuel supply valve **15** is more retarded than a valve opening timing IO of the intake valve **10**. In FIG. **4**, a dotted and dashed line indicates the effective opening area of the exhaust valve **14** (a throat area corresponding to a position of the exhaust valve **14** in the exhaust port **24**), a solid line indicates the effective opening area of the intake valve **10** (a throat area corresponding to a position of the intake valve **10** in the intake port **22**), and a dashed line indicates the effective opening area of the fuel supply valve **15** (a throat area corresponding to a position of the fuel supply valve **15** in the fuel supply port **26**). In FIG. **4**, EO indicates a valve opening timing of the exhaust valve **14**, EC indicates a valve closing timing of the exhaust valve **14**, FC indicates a valve closing timing of the fuel supply valve **15**, and IC indicates a valve closing timing of the intake valve **10**. Further, in the present specification, the “valve opening timing” means a timing at which the valve starts to open (a timing at which the effective opening area starts to increase from 0), and the “valve closing timing” means a timing at which the valve closes (a timing at which the effective opening area becomes 0).

[0062] Further, in the configuration shown in FIG. **3**, the distance g1 between the fuel supply valve arm **48** and the fuel supply valve **15** may be greater than 0 at the valve closing timing EC of the exhaust valve **14** in an exhaust stroke of the hydrogen engine **2** (see FIG. **4**).

[0063] According to the above-described hydrogen engine **2**, the fuel supply port **26** is disposed separately from the intake port **22**, and the fuel gas containing hydrogen is supplied to the combustion chamber **20** from the fuel supply port **26** without via the intake port **22**. Therefore, it is possible to suppress the occurrence of backfire in which a flame travels back to the intake port **22**.

[0064] Further, since the maximum value g1max of the distance g1 in the one combustion cycle of the hydrogen engine **2** is greater than the maximum value g2max of the distance g2 in said one combustion cycle of the hydrogen engine **2**, the valve opening timing FO of the fuel supply valve **15** can be more retarded than the valve opening timing IO of the intake valve **10**. Therefore, even if there is a period of overlap between a valve opening period of the intake valve **10** and a valve opening period of the exhaust valve **14** (a period from the valve opening timing IO of the intake valve **10** to the valve closing timing EC of the exhaust valve **14** in FIG. **4**), it is possible to suppress discharge of a part of the fuel gas supplied from the fuel supply port **26** to the combustion chamber **20** from the exhaust port **24** without being burned. Thus, it is possible to suppress a decrease in engine efficiency, and to implement the highly efficient hydrogen engine **2**. Further, since the distance g1 between the fuel supply valve arm **48** and the fuel supply valve **15** at the valve closing timing EC of the exhaust valve **14** is greater than **0**, the valve opening timing FO of the fuel supply valve **15** can be more retarded than the valve closing timing EC of the exhaust valve **14**. Therefore, it is possible to effectively suppress discharge of a part of the fuel gas supplied from the fuel supply port **26** to the combustion chamber **20** from the exhaust port **24** without being burned.

[0065] Each of FIGS. **5**A to **5**C is a view for describing an example of the detailed configuration of the fuel supply valve **15** shown in FIGS. **1** and **2**. FIG. **5**A shows a state in which the valve body portion **36** of the fuel supply valve **15** abuts against the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is closed. FIG. **5**B shows a state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is open. FIG. **5**C shows a state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** and the fuel supply port **26** is closed by a collar portion **50** of the fuel supply valve **15** (a state between the state shown in FIG. **5**A and the state shown in FIG. **5**B).

[0066] In the examples shown in FIGS. **5**A to **5**C, the fuel supply valve **15** includes the collar portion **50** in addition to the valve stem **34**, the valve body portion **36**, and the force receiving portion **38** which are described above. Further, the cylinder head **8** includes a cylinder head body **52**, and an annular valve seat member **56** forming the annular valve seat surface **54** of the fuel supply port **26** and configured separately from the cylinder head body **52**.

[0067] In the illustrated examples, the collar portion **50** is disposed adjacent to the valve body portion **36** between the valve stem **34** and the valve body portion **36** (an upper end of the valve body portion **36**), and is formed in a disk or columnar shape. An outer diameter of the collar portion **50** is greater than an outer diameter of the valve stem **34** and approximately coincides with a flow passage width of the fuel supply port **26**, that is, an inner diameter of the annular valve seat member **56**. The outer diameter of the collar portion **50** is set such that an outer peripheral surface of the collar portion **50** can slide on a flow passage wall **75** of the fuel supply port **26** (an inner peripheral surface of the valve seat member **56** in the illustrated examples). Further, in the state in which the valve body portion **36** abuts against the valve seat surface **54** of the fuel supply port **26** in the axial direction of the fuel supply valve **15** (see FIG. **5**A), the collar portion **50** is located upstream of a fuel gas flow in the axial direction of the fuel supply valve **15** relative to the valve seat surface **54**.

[0068] Herein, the collar portion **50** is configured to satisfy H1>0.7×L, where H1 is a height of the collar portion **50** in the axial direction of the fuel supply valve **15** as shown in FIG. **5**C and L1 is a lift amount of the fuel supply valve **15** at the valve closing timing EC of the exhaust valve **14** in the exhaust stroke of the hydrogen engine **2** (see FIG. **4**) as shown in FIG. **6**. Further, more preferably, the collar portion **50** is configured to satisfy H1>L. In FIG. **6**, the horizontal axis represents a crank angle of the hydrogen engine **2**, and the vertical axis means a lift amount of each of the exhaust valve **14** and the fuel supply valve **15**. Further, the above-described lift amount L shown in FIG. **6** means a distance between the valve seat surface **54** and the valve body portion **36** of the fuel supply valve **15** at the valve closing timing EC of the exhaust valve **14** in the exhaust stroke of the hydrogen engine **2** (see FIG. **4**).

[0069] According to the configuration including the above-described collar portion **50**, as shown in FIG. **5**C, even if the valve body portion **36** is separated from the valve seat surface **54**, it is possible to maintain the state in which the fuel supply port **26** is closed or the state in which the opening area of the fuel supply port **26** is small as long as the outer peripheral surface of the collar portion **50** abuts against the flow passage wall **75** of the fuel supply port **26**. Therefore, the fuel gas is not supplied to the combustion chamber **20** at an initial stage of the lift of the fuel supply valve **15**. Whereby, the valve opening timing FO of the fuel supply valve **15** can be more retarded than the valve opening timing IO of the intake valve **10**. Therefore, even if there is the period of overlap between the valve opening period of the intake valve **10** and the valve opening period of the exhaust valve **14** (the period from the valve opening timing IO of the intake valve **10** to the valve closing timing EC of the exhaust valve **14** in FIG. **4**), it is possible to suppress discharge of a part of the fuel gas supplied from the fuel supply port **26** to the combustion chamber **20** from the exhaust port **24** without being burned. Thus, it is possible to suppress the decrease in engine efficiency, and to implement the highly efficient hydrogen engine **2**.

[0070] Further, as described above, by providing the fuel supply valve **15** with the collar portion **50** satisfying H1>0.7L (more preferably by satisfying H1>L), the valve opening timing

[0071] FO of the fuel supply valve **15** can be more retarded than the valve closing timing EC of the exhaust valve **14**. Therefore, it is possible to effectively suppress discharge of a part of the fuel gas supplied from the fuel supply port **26** to the combustion chamber **20** from the exhaust port **24** without being burned.

[0072] Each of FIGS. **7**A to **7**C is a view for describing an example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**. FIG. **7**A shows the state in which the valve body portion **36** of the fuel supply valve **15** abuts against the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is closed. FIG. **7**B shows the state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is open. FIG. **7**C shows a state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** and the valve body portion **36** of the fuel supply valve **15** is in contact with the inner peripheral surface of the valve seat member **56** (a state between the state shown in FIG. **7**A and the state shown in FIG. **7**B).

[0073] In the examples shown in FIGS. **7**A to **7**C, the fuel supply port **26** includes a first flow passage portion **60** disposed along the axial direction of the fuel supply valve **15**, the valve seat surface **54** disposed downstream of the first flow passage portion **60**, and a second flow passage portion **62** disposed downstream of the valve seat surface **54** and having a flow passage width W2 greater than a flow passage width W1 of the first flow passage portion **60**. In the illustrated example, a step **65** is formed between the valve seat surface **54** and an opening end **63** on an outlet side of the fuel supply port **26**.

[0074] An outer diameter D of the valve body portion **36** approximately coincides with the flow passage width W2 of the second flow passage portion **62**, and a downstream end edge **55** (maximum outer diameter portion) of the outer peripheral surface **53** (the above-described inclined surface **53**) of the valve body portion **36** of the fuel supply valve **15** is configured to slide on a flow passage wall **64** of the second flow passage portion **62**. The outer diameter D of the valve body portion **36** means a maximum value of the outer diameter of the valve body portion **36**, and in the illustrated example means the outer diameter of the valve body portion **36** at a lower end of the valve body portion **36**.

[0075] Herein, the second flow passage portion **62** is configured to satisfy H2>0.7L, where H2 is a length of the second flow passage portion **62** (a height of the above-described step **65**) in the axial direction of the fuel supply valve **15** as shown in FIG. **7**C and L is the lift amount of the fuel supply valve **15** at the valve closing timing EC of the exhaust valve **14** in the exhaust stroke of the hydrogen engine **2** as shown in FIG. **6**. Further, more preferably, the second flow passage portion **62** is configured to satisfy H2>L.

[0076] According to the configurations shown in FIGS. **7**A to **7**C, the second flow passage portion **62** having the flow passage width W2 greater than the flow passage width W1 of the first flow passage portion **60** is disposed downstream of the valve seat surface **54**, and the outer peripheral surface **53** of the valve body portion **36** is configured to slide on the flow passage wall **64** of the second flow passage portion **62**. Therefore, as shown in FIG. **7**C, even if the valve body portion **36** is separated from the valve seat surface **54**, it is possible to maintain the state in which the fuel supply port **26** is closed or the state in which the opening area of the fuel supply port **26** is small as long as the outer peripheral surface **53** of the valve body portion **36** slides on the flow passage wall **64** of the second flow passage portion **62**. Whereby, the valve opening timing FO of the fuel supply valve **15** can be more retarded than the valve opening timing IO of the intake valve **10**. Therefore, even if there is the period of overlap between the valve opening period of the intake valve **10** and the valve opening period of the exhaust valve **14**, it is possible to suppress discharge of a part of the fuel gas supplied from the fuel supply port **26** to the combustion chamber **20** from the exhaust port **24** without being burned. Thus, it is possible to suppress the decrease in engine efficiency, and to implement the highly efficient hydrogen engine **2**.

[0077] Further, as described above, by satisfying H2>0.7L (more preferably by satisfying H2>L), the valve opening timing FO of the fuel supply valve **15** can be more retarded than the valve closing timing EC of the exhaust valve **14**. Therefore, it is possible to effectively suppress discharge of a part of the fuel gas supplied from the fuel supply port **26** to the combustion chamber **20** from the exhaust port **24** without being burned.

[0078] Each of FIGS. **8**A to **8**C is a view for describing another example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**. FIG. **8**A shows the state in which the valve body portion **36** of the fuel supply valve **15** abuts against the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is closed. FIG. **8**B shows the state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is open. FIG. **8**C shows the state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is open (a state between the state shown in FIG. **8**A and the state shown in FIG. **8**B).

[0079] In the configurations shown in FIGS. **8**A to **8**C, the fuel supply port **26** includes the first flow passage portion **60** disposed along the axial direction of the fuel supply valve **15**, the valve seat surface **54** disposed downstream of the first flow passage portion **60**, and the second flow passage portion **62** disposed downstream of the valve seat surface **54** and having the flow passage width W2 greater than the flow passage width W1 of the first flow passage portion **60** (see FIG.

8A). In the illustrated example, the step **65** is formed between the valve seat surface **54** and the opening end **63** on the outlet side of the fuel supply port **26**. Further, the flow passage width W2 of the second flow passage portion **62** is greater than the outer diameter D of the valve body portion **36** (see FIG. **8**A). The outer diameter D of the valve body portion **36** means the maximum value of the outer diameter of the valve body portion **36**, and in the illustrated example means the outer diameter of the valve body portion **36** at the lower end of the valve body portion **36**.

[0080] Further, as shown in FIG. **8**A, in the state in which the fuel supply valve **15** abuts against the valve seat surface **54** disposed in the fuel supply port **26**, the lower surface **66** of the fuel supply valve **15** is located upstream, that is, on an upper side of the fuel gas flow in the axial direction of the fuel supply valve **15** relative to the lower surface **9** of the cylinder head **8**.

[0081] Further, the second flow passage portion **62** is configured to satisfy H3>L, where H3 is a distance between the lower surface **66** of the fuel supply valve **15** and the lower surface **9** of the cylinder head **8** in the axial direction of the fuel supply valve **15** in the state in which the fuel supply valve **15** abuts against the valve seat surface **54** disposed in the fuel supply port **26** as shown in FIG. **8**A and L is the lift amount of the fuel supply valve **15** at the valve closing timing EC of the exhaust valve **14** in the exhaust stroke of the hydrogen engine **2** as shown in FIG. **6**.

[0082] According to the configurations shown in FIGS. **8**A to **8**C, as shown in FIG. **8**C, even if the valve body portion **36** is separated from the valve seat surface **54**, the fuel gas flows in the second flow passage portion **62** and then is supplied to the combustion chamber **20**. Therefore, it is possible to delay a time for the fuel gas to reach the position of the exhaust valve **14**. Therefore, even if there is the period of overlap between the valve opening period of the intake valve **10** and the valve opening period of the exhaust valve **14** (the period from the valve opening timing IO of the intake valve **10** to the valve closing timing EC of the exhaust valve **14** in FIG. **4**), it is possible to suppress discharge of a part of the fuel gas supplied from the fuel supply port **26** to the combustion chamber **20** from the exhaust port **24** without being burned. Thus, it is possible to suppress the decrease in engine efficiency, and to implement the highly efficient hydrogen engine **2**.

[0083] Further, by satisfying H3>L as described above, the valve opening timing FO of the fuel supply valve **15** can be more retarded than the valve closing timing EC of the exhaust valve **14**. Therefore, it is possible to effectively suppress discharge of a part of the fuel gas supplied from the fuel supply port **26** to the combustion chamber **20** from the exhaust port **24** without being burned.

[0084] Each of FIGS. **9**A to **9**C is a view for describing another example of the detailed configuration of the fuel supply valve **15** shown in FIGS. **1** and **2**. FIG. **9**A shows the state in which the valve body portion **36** of the fuel supply valve **15** abuts against the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is closed. FIG. **9**B shows the state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** of the fuel supply port **26** and the fuel supply port **26** is open. FIG. **9**C shows a state in which the valve body portion **36** of the fuel supply valve **15** is separated from the valve seat surface **54** and at least a part of an outlet portion **70** of the fuel supply port **26** on an exhaust port **24** side is covered by the collar portion **72** (cover portion) of the fuel supply valve **15** (a state between the state shown in FIG. **9**A and the state shown in FIG. **9**B).

[0085] In the configurations shown in FIGS. **9**A to **9**C, the collar portion **72** is disposed adjacent to the valve body portion **36** between the valve stem **34** and the valve body portion **36** (the upper end of the valve body portion **36**), has a fan shape when viewed in the axial direction of the fuel supply valve **15**, and is disposed so as to protrude from the valve stem **34** in the radial direction of the valve stem **34**. The amount of the protrusion of the collar portion **72** from the valve stem **34** in the radial direction of the valve stem **34** (the length of the chord of the above-described fan shape) may be set such that the outer peripheral surface of the collar portion **72** can slide on the flow passage wall of the fuel supply port **26** (the inner peripheral surface of the valve seat member **56**). Further, in the state in which the valve body portion **36** abuts against the valve seat surface **54** of the fuel supply port **26** in the axial direction of the fuel supply valve **15** (see FIG. **9**A), the collar portion **72** is located upstream of the fuel gas flow in the axial direction of the fuel supply valve **15** relative to the valve seat surface **54**.

[0086] In the configurations shown in FIGS. **9**A to **9**C, the collar portion **72** is configured to cover at least a part of the outlet portion **70** of the fuel supply port **26** on the exhaust port **24** side in at least a part of the valve opening period of the fuel supply valve **15**. Whereby, at the initial stage of the lift operation of the fuel supply valve **15**, it possible to prevent the fuel gas flow from the fuel supply port **26** to the exhaust port **24** side, and to introduce the fuel gas from the fuel supply port **26** to an intake port **22** side. Therefore, it is possible to suppress slip out of the fuel gas from the fuel supply port **26** to the exhaust port **24** side in the valve opening period of the exhaust valve **14**. In the configuration including the above-described collar portion **72**, a rotation stopper may be provided to prevent the rotation of the fuel supply valve **15**. The rotation stopper may be implemented by, for example, providing a notch in the valve stem **34** of the fuel supply valve **15** and providing in the cylinder head **8** an engagement portion engaging with the notch.

[0087] Further, for example, as shown in FIG. **10**A, the collar portion **72** may be disposed in a range S**1** on the exhaust port **24** side in the circumferential direction around an axis C**3** of the fuel supply valve **15** (the central axis of the valve stem **34**). In the example shown in FIG. **10**A, a side on which two intake ports **22** are arranged is defined as the intake port **22** side and a side on which two exhaust ports **24** are arranged is defined as the exhaust port **24** side with respect to a plane K including the axis C**3** of the fuel supply valve **15**.

[0088] Further, for example, as shown in FIG. **10**B, the collar portion **72** may be disposed in a range of not less than 180°, which includes the range SI on the exhaust port **24** side, in the circumferential direction around the axis C**3** of the fuel supply valve **15**. In the example shown in FIG. **10**B, the collar portion **72** is disposed over the range S**1** on the exhaust port **24** side and the range S**2** adjacent to an upstream side of the range S**1** in a swirl direction of a swirling flow of intake air flowing into the combustion chamber **20** from the intake ports **22**, in the circumferential direction around the axis of the fuel supply valve **15**.

[0089] More specifically, where a strength S of the swirling flow is a dimensionless number indicating how many times the swirling flow of the intake air flowing into the combustion chamber **20** from the intake ports **22** rotates about the combustion chamber **20** during one rotation of the hydrogen engine **2**, an angular width OL is a width of the crank angle, which corresponds to, of one combustion cycle of the hydrogen engine **2**, the period of overlap between the valve opening period of the exhaust valve **14** and the valve opening period of the fuel supply valve **15** (a width of the crank angle from the valve opening timing FO of the fuel supply valve **15** to the valve closing timing EC of the exhaust valve **14** in FIG. **6**), and an angle θ is a product of the strength S of the swirling flow and the angular width OL, the collar portion **72** may be configured in a range including, in the circumferential direction around the axis C**3** of the fuel supply valve **15**, the range S**1** on the exhaust port **24** side and the range S**2** of the angle θ from an upstream end in a rotational direction of the swirling flow in the range S**1** to the upstream side in the rotational direction of the swirling flow. Whereby, in consideration of the strength S of the swirling flow of the intake air flowing into the combustion chamber **20**, it is possible to effectively suppress slip out of the fuel gas from the fuel supply port **26** to the exhaust port **24** side in the valve opening period of the exhaust valve **14**.

[0090] FIG. **11** is a view for describing yet another example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**.

[0091] In the configuration shown in FIG. **11**, the cylinder head **8** includes the cylinder head body **52**, the annular valve seat member **56** forming the valve seat surface **54** of the fuel supply port **26** and configured separately from the cylinder head body **52**, and a mask plate **74** located between the cylinder head body **52** and the valve seat member **56** in the axial direction of the fuel supply valve **15**.

[0092] The mask plate **74** is located upstream of the fuel gas flow relative to the valve seat member **56** in the axial direction of the fuel supply valve **15**, and is interposed between the cylinder head body **52** and the valve seat member **56**. The mask plate **74** has a fan shape when viewed in the axial direction of the fuel supply valve **15**, and includes a protruding portion **76** (cover portion) protruding from the flow passage wall **75** of the fuel supply port **26** toward the valve stem **34**. The amount of the protrusion of the mask plate **74** from the flow passage wall **75** in the radial direction of the valve stem **34** (the length of the chord of the above-described fan shape) may be set to a protrusion amount that allows an inner peripheral edge of the mask plate **74** to slide on the outer peripheral surface of the valve stem **34**.
[0093] The protruding portion **76** of the mask plate **74** is configured to cover at least a part of the outlet portion **70** of the fuel supply port **26** on the exhaust port **24** side. Whereby, since the fuel gas is less likely to flow from the fuel supply port **26** to the exhaust port **24** side, it is possible to suppress discharge of a part of the fuel gas supplied from the fuel supply port **26** to the combustion chamber **20** from the exhaust port **24** without being burned. Further, compared to the configurations shown in FIGS. **9**A to **9**C, by reducing the weight of the fuel supply valve **15**, it is possible to improve responsiveness of the fuel supply valve **15** and to facilitate manufacture or quality control of the fuel supply valve **15**. Furthermore, since the fuel gas is less likely to be supplied to the exhaust port **24** side regardless of the lift amount of the fuel supply valve **15**, a fuel distribution within the cylinder **4** becomes such that a fuel concentration is high on the intake side and the fuel concentration is low on the exhaust side. Thus, since the intake side burns before the exhaust side, it is possible to suppress knocking (if the fuel concentration is uniform, since the exhaust side having a high temperature burns first and the intake side burns over time, an end gas left on a low-temperature wall surface on the intake side self-ignites finally, causing knocking).
[0094] In the configuration having the above-described mask plate **74**, for example, as shown in FIG. **12**A, the protruding portion **76** of the mask plate **74** may be disposed in the range S**1** on the exhaust port **24** side in the circumferential direction around the axis C of the fuel supply valve **15**. In the example shown in FIG. **12**A, the side on which the two intake ports **22** are arranged is defined as the intake port **22** side and the side on which the two exhaust ports **24** are arranged is defined as the exhaust port **24** side with respect to the plane K including the axis C of the fuel supply valve **15**.
[0095] Further, for example, as shown in FIG. **12**B, the protruding portion **76** of the mask plate **74** may be disposed in the range of not less than 180°, which includes the range S**1** on the exhaust port **24** side, in the circumferential direction around the axis of the fuel supply valve **15**. In the example shown in FIG. **12**B, the protruding portion **76** of the mask plate **74** is disposed over the range S**1** on the exhaust port **24** side and the range S**2** adjacent to the upstream side of the range S**1** in the swirl direction of the swirling flow of the intake air flowing into the combustion chamber from the intake ports, in the circumferential direction around the axis of the fuel supply valve **15**. More specifically, where the angle θ is the above-described product of the strength S of the swirling flow and the angular width OL, the protruding portion **76** of the mask plate **74** may be configured in the range including, in the circumferential direction around the axis C of the fuel supply valve **15**, the range SI on the exhaust port **24** side and the range S**2** of the angle θ from the upstream end in the rotational direction of the swirling flow in the range S**1** to the upstream side in the rotational direction of the swirling flow. Whereby, in consideration of the strength S of the swirling flow of the intake air flowing into the combustion chamber **20**, it is possible to effectively suppress slip out of the fuel gas from the fuel supply port **26** to the exhaust port **24** side in the valve opening period of the exhaust valve.
[0096] FIG. **13** is a view for describing yet another example of the detailed configuration of the cylinder head **8** shown in FIGS. **1** and **2**.
[0097] In the configuration shown in FIG. **13**, the annular valve seat member **56** includes a protruding portion **77** (cover portion) protruding from the flow passage wall **75** of the fuel supply

port **26** toward the valve stem **34**. The amount of the protrusion of the valve seat member **56** from the flow passage wall **75** in the radial direction of the valve stem **34** (the length of the chord of the above-described fan shape) may be set to a protrusion amount that allows the protruding portion **77** of the valve seat member **56** to slide on the outer peripheral surface of the valve stem **34**.

[0098] The protruding portion **77** of the valve seat member **56** is configured to cover at least a part of the outlet portion **70** of the fuel supply port **26** on the exhaust port **24** side. Whereby, since the fuel gas is less likely to flow from the fuel supply port **26** to the exhaust port **24** side, it is possible to suppress discharge of a part of the fuel gas supplied from the fuel supply port **26** to the combustion chamber **20** from the exhaust port **24** without being burned. Further, compared to the configurations shown in FIGS. **9**A to **9**C, by reducing the weight of the fuel supply valve **15**, it is possible to improve responsiveness of the fuel supply valve **15** and to facilitate manufacture or quality control of the fuel supply valve **15**. Furthermore, since the fuel gas is less likely to be supplied to the exhaust port **24** side regardless of the lift amount of the fuel supply valve **15**, a fuel distribution within the cylinder **4** becomes such that the fuel concentration is high on the intake side and the fuel concentration is low on the exhaust side. Thus, since the intake side burns before the exhaust side, it is possible to suppress knocking (if the fuel concentration is uniform, since the exhaust side having the high temperature burns first and the intake side burns over time, the end gas left on the low-temperature wall surface on the intake side self-ignites finally, causing knocking). Further, the number of parts can be reduced as compared to the configuration shown in FIG. **11**.

[0099] In the case where the protruding portion **77** of the valve seat member **56** described above is disposed, for example, as shown in FIG. **14**A, the protruding portion **77** of the valve seat member **56** may be disposed in the range SI on the exhaust port **24** side in the circumferential direction around the axis C of the fuel supply valve **15**. In the example shown in FIG. **14**A, the side on which the two intake ports **22** are arranged is defined as the intake port **22** side and the side on which the two exhaust ports **24** are arranged is defined as the exhaust port **24** side with respect to the plane K including the axis C of the fuel supply valve **15**.

[0100] Further, for example, as shown in FIG. **14**B, the protruding portion **77** of the valve seat member **56** may be disposed in the range of not less than 180°, which includes the range S**1** on the exhaust port **24** side, in the circumferential direction around the axis of the fuel supply valve **15**. In the example shown in FIG. **14**B, the protruding portion **77** of the valve seat member **56** is disposed over the range SI on the exhaust port **24** side and the range S**2** adjacent to the upstream side of the range S**1** in the swirl direction of the swirling flow of the intake air flowing into the combustion chamber from the intake ports, in the circumferential direction around the axis of the fuel supply valve **15**. More specifically, where the angle θ is the above-described product of the strength S of the swirling flow and the angular width OL, the protruding portion **77** of the valve seat member **56** may be configured in the range including the range S**1** on the exhaust port **24** side and the range S**2** of the angle θ from the upstream end in the rotational direction of the swirling flow in the range S**1** to the upstream side in the rotational direction of the swirling flow. Whereby, in consideration of the strength S of the swirling flow of the intake air flowing into the combustion chamber **20**, it is possible to effectively suppress slip out of the fuel gas from the fuel supply port **26** to the exhaust port **24** side in the valve opening period of the exhaust valve.

[0101] The present disclosure is not limited to the above-described embodiments, and also includes an embodiment obtained by modifying the above-described embodiments or an embodiment obtained by combining these embodiments as appropriate.

[0102] The contents described in the above embodiments would be understood as follows, for instance.

[0103] (1) A hydrogen engine according to at least one embodiment of the present disclosure is a hydrogen engine (such as the above-described hydrogen engine **2**) using fuel gas containing hydrogen, including: a cylinder (such as the above-described cylinder **4**); a piston (such as the above-described piston **6**) movable within the cylinder; a cylinder head (such as the above-described cylinder head **8**) forming a combustion chamber (such as the above-described combustion chamber **20**) with the piston, and including an intake port (such as the above-described intake port **22**) connected to the combustion chamber and a fuel supply port (such as the above-described fuel supply port **26**) connected to the combustion chamber; an intake valve (such as the above-described intake valve **10**) for opening and closing the intake port; a fuel supply valve (such as the above-described fuel supply valve **15**) for opening and closing the fuel supply port; and a valve train (such as the above-described valve train **18**) commonly provided for the intake valve and the fuel supply valve, and configured to open and close the intake valve and the fuel supply valve in conjunction with each other. The hydrogen engine is configured such that a valve opening timing (such as the above-described valve opening timing FO) of the fuel supply valve is more retarded than a valve opening timing (such as the above-described valve opening timing IO) of the intake valve.

[0104] According to the hydrogen engine as defined in the above (1), the fuel supply port is disposed separately from the intake port, and the fuel gas is supplied to the combustion chamber from the fuel supply port without via the intake port. Therefore, it is possible to suppress the occurrence of backfire in which a flame travels back to the intake port. Further, since the valve opening timing of the fuel supply valve is more retarded than the valve opening timing of the intake valve, even if there is the period of overlap between the valve opening period of the intake valve and the valve opening period of the exhaust valve, it is possible to suppress discharge of a part of the fuel gas supplied from the fuel supply port to the combustion chamber from the exhaust port without being burned. Thus, it is possible to suppress the decrease in engine efficiency, and to implement the highly efficient hydrogen engine. Therefore, it is possible to suppress the occurrence of backfire and to achieve high engine efficiency.

[0105] (2) In some embodiments, in the hydrogen engine as defined in the above (1), the valve train includes: an intake rocker arm (such as the above-described intake rocker arm **44**) configured to rotate around a predetermined rotational axis (such as the above-described rotational axis C**2**) and to press the intake valve; and a fuel supply valve arm (such as the above-described fuel supply valve arm **48**) configured to rotate around the rotational axis together with the intake rocker arm and to press the fuel supply valve, and a maximum value (such as the above-described maximum value g1max) of a distance between the fuel supply valve arm and the fuel supply valve in one combustion cycle of the engine is greater than a maximum value (such as the above-described maximum value g2max) of a distance between the intake rocker arm and the intake valve in the one combustion cycle of the engine.

[0106] According to the hydrogen engine as defined in the above (2), since the maximum value of the distance between the fuel supply valve arm and the fuel supply valve in the one combustion cycle of the engine is greater than the maximum value of the distance between the intake rocker arm and the intake valve in the one combustion cycle of the engine, the valve opening timing of the fuel supply valve can be more retarded than the valve opening timing of the intake valve. Therefore, with the simple configuration, it is possible to achieve the effect as defined in the above (1).

[0107] (3) In some embodiments, in the hydrogen engine as defined in the above (2), the distance (such as the above-described distance g1) between the fuel supply valve arm and the fuel supply valve at a valve closing timing (such as the above-described valve closing timing EC) of an exhaust valve of the engine is greater than 0.

[0108] According to the hydrogen engine as defined in the above (3), since the distance between the fuel supply valve arm and the fuel supply valve at the valve closing timing of the exhaust valve is greater than 0, the valve opening timing of the fuel supply valve can be more retarded than the valve closing timing of the exhaust valve. Therefore, it is possible to effectively suppress discharge of a part of the fuel gas supplied from the fuel supply port to the combustion chamber from the

exhaust port without being burned.
[0109] (4) In some embodiments, in the hydrogen engine as defined in any of the above (1) to (3), the fuel supply valve includes: a valve stem (such as the above-described valve stem **34**); a valve body portion (such as the above-described valve body portion **36**) disposed on one end side of the valve stem and abuttable against a valve seat surface of the fuel supply port in an axial direction of the valve stem; and a collar portion (such as the above-described collar portion **50**) disposed between the valve stem and the valve body portion, and located upstream of a flow of the fuel gas in an axial direction of the fuel supply valve relative to the valve seat surface of the fuel supply port in a state in which the valve body portion abuts against the valve seat surface.
[0110] According to the hydrogen engine as defined in the above (4), since the above-described collar portion is disposed in the fuel supply valve, the valve opening timing of the fuel supply valve can be more retarded than the valve opening timing of the intake valve. Therefore, with the simple configuration, it is possible to achieve the effect as defined in the above (1).
[0111] (5) In some embodiments, in the hydrogen engine as defined in the above (4), $H1>0.7L$ is satisfied, where L is a lift amount of the fuel supply valve at a valve closing timing of an exhaust valve of the engine and H1 is a height of the collar portion.
[0112] According to the hydrogen engine as defined in the above (5), since the fuel supply valve includes the collar portion satisfying $H1>0.7L$, the valve opening timing of the fuel supply valve can be more retarded than the valve closing timing of the exhaust valve. Therefore, it is possible to effectively suppress discharge of a part of the fuel gas supplied from the fuel supply port to the combustion chamber from the exhaust port without being burned.
[0113] (6) In some embodiments, in the hydrogen engine as defined in any of the above (1) to (5), the fuel supply port includes: a first flow passage portion (such as the above-described first flow passage portion **60**) disposed along an axial direction of the fuel supply valve; a valve seat surface (such as the above-described valve seat surface **54**) disposed downstream of the first flow passage portion; and a second flow passage portion (such as the above-described second flow passage portion **62**) disposed downstream of the valve seat surface and having a flow passage width greater than a flow passage width of the first flow passage portion, and an outer peripheral surface of a valve body portion of the fuel supply valve is configured to slide on a flow passage wall (such as the above-described flow passage wall **64**) of the second flow passage portion.
[0114] According to the hydrogen engine as defined in the above (6), even if the valve body portion is separated from the valve seat surface, it is possible to maintain the state in which the fuel supply port is closed as long as the outer peripheral surface of the valve body portion slides on the flow passage wall of the second flow passage portion. Whereby, the valve opening timing of the fuel supply valve can be more retarded than the valve opening timing of the intake valve. Therefore, with the simple configuration, it is possible to achieve the effect as defined in the above (1). Further, since the weight of the fuel supply valve can be reduced compared to the configuration as defined in (4), it is possible to improve responsiveness of the fuel supply valve.
[0115] (7) In some embodiments, in the hydrogen engine as defined in the above (6), $H2>0.7L$ is satisfied, where L is a lift amount of the fuel supply valve at a valve closing timing of an exhaust valve of the engine and H2 is a length of the second flow passage portion in an axial direction of the fuel supply valve.
[0116] According to the hydrogen engine as defined in the above (7), since $H2>0.7L$ is satisfied, the valve opening timing of the fuel supply valve can be more retarded than the valve closing timing of the exhaust valve. Therefore, it is possible to effectively suppress discharge of a part of the fuel gas supplied from the fuel supply port to the combustion chamber from the exhaust port without being burned.
[0117] (8) A hydrogen engine according to at least one embodiment of the present disclosure is a hydrogen engine (such as the above-described hydrogen engine **2**) using fuel gas containing hydrogen, including: a cylinder (such as the above-described cylinder **4**); a piston (such as the

above-described piston **6**) movable within the cylinder; a cylinder head forming a combustion chamber (such as the above-described combustion chamber **20**) with the piston, and including an intake port (such as the above-described intake port **22**) connected to the combustion chamber, a fuel supply port (such as the above-described fuel supply port **26**) connected to the combustion chamber, and an exhaust port (such as the above-described exhaust port **24**) connected to the combustion chamber; an intake valve (such as the above-described intake valve **10**) for opening and closing the intake port; a fuel supply valve (such as the above-described fuel supply valve **15**) for opening and closing the fuel supply port; a valve train (such as the above-described valve train **18**) commonly provided for the intake valve and the fuel supply valve, and configured to open and close the intake valve and the fuel supply valve in conjunction with each other; and a cover portion (such as the above-described collar portion **72**, protruding portion **76**, or protruding portion **77**) configured to cover at least a part of an outlet portion of the fuel supply port on a side of the exhaust port in at least a part of a valve opening period of the fuel supply valve.

[0118] According to the hydrogen engine as defined in the above (8), since at least a part of the outlet portion of the fuel supply port on the side of the exhaust port is covered by the cover portion in at least a part of the valve opening period of the fuel supply valve, the fuel gas is less likely to flow from the fuel supply valve to the side of the exhaust port. Therefore, it is possible to suppress discharge of a part of the fuel gas supplied from the fuel supply port to the combustion chamber from the exhaust port without being burned.

[0119] (9) In some embodiments, in the hydrogen engine as defined in the above (8), the cover portion is a collar portion (such as the above-described collar portion **72**) disposed between a valve stem of the fuel supply valve and a valve body portion, and the collar portion is formed in a disk or columnar shape, is located upstream of a flow of the fuel gas in an axial direction of the fuel supply valve relative to a valve seat surface of the fuel supply port in a state in which a valve body portion of the fuel supply valve abuts against the valve seat surface, and has an outer diameter greater than an outer diameter of the valve stem.

[0120] According to the hydrogen engine as defined in the above (9), the fuel gas flow from the fuel supply port to the exhaust port side can be suppressed by the collar portion. Therefore, with the simple configuration, it is possible to achieve the effect as defined in the above (8).

[0121] (10) In some embodiments, in the hydrogen engine as defined in the above (8), the cylinder head includes: a cylinder head body (such as the above-described cylinder head body **52**); a valve seat member (such as the above-described valve seat member **56**) forming a valve seat surface of the fuel supply port and configured separately from the cylinder head body; and a mask plate (such as the above-described mask plate **74**) interposed between the cylinder head body and the valve seat member, the mask plate includes a protruding portion (such as the above-described protruding portion **76**) protruding from a flow passage wall of the fuel supply port toward a valve stem of the fuel supply valve, and the cover portion is the protruding portion.

[0122] According to the hydrogen engine as defined in the above (10), the fuel gas flow from the fuel supply port to the exhaust port side can be suppressed by the protruding portion of the mask plate. Therefore, with the simple configuration, it is possible to achieve the effect as defined in the above (8). Further, compared to the configuration of the above (9), by reducing the weight of the fuel supply valve, it is possible to improve responsiveness of the fuel supply valve and to facilitate manufacture or quality control of the fuel supply valve. Furthermore, since the fuel gas is less likely to be supplied to the exhaust port side regardless of the lift amount of the fuel supply valve, a fuel distribution within the cylinder becomes such that the fuel concentration is high on the intake side and the fuel concentration is low on the exhaust side. Thus, since the intake side burns before the exhaust side, it is possible to suppress knocking (if the fuel concentration is uniform, since the exhaust side having the high temperature burns first and the intake side burns over time, the end gas left on the low-temperature wall surface on the intake side self-ignites finally, causing knocking).

[0123] (11) In some embodiments, in the hydrogen engine as defined in the above (8), the cylinder head includes: a cylinder head body (such as the above-described cylinder head body **52**); and a valve seat member (such as the above-described valve seat member **56**) forming a valve seat surface of the fuel supply port and configured separately from the cylinder head body, the valve seat member includes a protruding portion (such as the above-described protruding portion **77**) protruding from a flow passage wall of the fuel supply port toward a valve stem of the fuel supply valve, and the cover portion is the protruding portion.

[0124] According to the hydrogen engine as defined in the above (11), the fuel gas flow from the fuel supply port to the exhaust port side can be suppressed by the protruding portion of the valve seat member. Therefore, with the simple configuration, it is possible to achieve the effect as defined in the above (8). Further, compared to the configuration of the above (9), by reducing the weight of the fuel supply valve, it is possible to improve responsiveness of the fuel supply valve and to facilitate manufacture or quality control of the fuel supply valve. Furthermore, since the fuel gas is less likely to be supplied to the exhaust port side regardless of the lift amount of the fuel supply valve, the fuel distribution within the cylinder becomes such that the fuel concentration is high on the intake side and the fuel concentration is low on the exhaust side. Thus, since the intake side burns before the exhaust side, it is possible to suppress knocking (if the fuel concentration is uniform, since the exhaust side having the high temperature burns first and the intake side burns over time, the end gas left on the low-temperature wall surface on the intake side self-ignites finally, causing knocking). Further, the number of parts can be reduced as compared to the above configuration (10).

[0125] (12) In some embodiments, in the hydrogen engine as defined in any of the above (8) to (11), where a strength S of a swirling flow of intake air flowing into the combustion chamber from the intake port is a dimensionless number indicating how many times the swirling flow rotates about the combustion chamber during one rotation of the engine, an angular width OL is a width of a crank angle, which corresponds to, of one combustion cycle of the engine, a period of overlap between a valve opening period of an exhaust valve of the engine and a valve opening period of the fuel supply valve, and an angle θ is a product of the strength S of the swirling flow and the angular width OL, and where S**1** is a range on a side of the exhaust port and S**2** is a range of the angle θ from an upstream end in a rotational direction of the swirling flow in the range SI to an upstream side in the rotational direction of the swirling flow, in a circumferential direction around an axis of the fuel supply valve, the cover portion is disposed in a range including the range S**1** and the range S**2** in the circumferential direction.

[0126] According to the hydrogen engine as defined in the above (12), in consideration of the strength S of the swirling flow of the intake air flowing into the combustion chamber, it is possible to effectively suppress slip out of the fuel gas from the fuel supply port to the exhaust port side in the valve opening period of the exhaust valve.

[0127] (13) A hydrogen engine according to at least one embodiment of the present disclosure is a hydrogen engine (such as the above-described hydrogen engine **2**) using fuel gas containing hydrogen, including: a cylinder (such as the above-described cylinder **4**); a piston (such as the above-described piston **6**) movable within the cylinder; a cylinder head (such as the above-described cylinder head **8**) forming a combustion chamber (such as the above-described combustion chamber **20**) with the piston, and including an intake port (such as the above-described intake port **22**) connected to the combustion chamber, a fuel supply port (such as the above-described fuel supply port **26**) connected to the combustion chamber, and an exhaust port (such as the above-described exhaust port **24**) connected to the combustion chamber; an intake valve (such as the above-described intake valve **10**) for opening and closing the intake port; a fuel supply valve (such as the above-described fuel supply valve **15**) for opening and closing the fuel supply port; and a valve train (such as the above-described valve train **18**) commonly provided for the intake valve and the fuel supply valve, and configured to open and close the intake valve and the fuel

supply valve in conjunction with each other. A lower surface of the cylinder head is formed along a plane. A lower surface (such as the above-described lower surface **66**) of the fuel supply valve is located upstream of a flow of the fuel gas in an axial direction of the fuel supply valve relative to the lower surface (such as the above-described lower surface **9**) of the cylinder head, in a state in which the fuel supply valve abuts against a valve seat surface disposed in the fuel supply port.
[0128] According to the hydrogen engine as defined in the above (13), since the lower surface of the fuel supply valve is located upstream of the flow of the fuel gas relative to the lower surface of the cylinder head in the state in which the fuel supply valve abuts against the valve seat surface disposed in the fuel supply port, a time from when the fuel supply valve opens until the fuel gas reaches an exhaust valve position can be longer than in the case where the lower surface of the fuel supply valve is located downstream of the flow of the fuel gas relative to the lower surface of the cylinder head. Therefore, even if there is the period of overlap between the valve opening period of the intake valve and the valve opening period of the exhaust valve, it is possible to suppress discharge of a part of the fuel gas supplied from the fuel supply port to the combustion chamber from the exhaust port without being burned. Thus, it is possible to suppress the decrease in engine efficiency, and to implement the highly efficient hydrogen engine.
[0129] (14) In some embodiments, in the hydrogen engine as defined in the above (13), H3>L is satisfied, where L is a lift amount of the fuel supply valve at a valve closing timing of an exhaust valve of the engine and H3 is a distance between the lower surface of the fuel supply valve and the lower surface of the cylinder head in the axial direction of the fuel supply valve in the state in which the fuel supply valve abuts against the valve seat surface disposed in the fuel supply port.
[0130] According to the hydrogen engine as defined in the above (14), since H3>L is satisfied, the valve opening timing of the fuel supply valve can be more retarded than the valve closing timing of the exhaust valve. Therefore, it is possible to effectively suppress discharge of a part of the fuel gas supplied from the fuel supply port to the combustion chamber from the exhaust port without being burned.
REFERENCE SIGNS LIST
[0131] **2** Hydrogen engine [0132] **4** Cylinder [0133] **6** Piston [0134] **8** Cylinder head [0135] **9** Lower surface [0136] **10** Intake valve [0137] **12**, **16** Valve spring [0138] **14** Exhaust valve [0139] **15** Fuel supply valve [0140] **18** Valve train [0141] **20** Combustion chamber [0142] **22** Intake port [0143] **24** Exhaust port [0144] **26** Fuel supply port [0145] **28**, **34** Valve stem [0146] **30**, **36** Valve body portion [0147] **32**, **38** Force receiving portion [0148] **40** Intake camshaft [0149] **41** Intake cam [0150] **42** Push rod [0151] **44** Intake rocker arm [0152] **44***a* One end portion [0153] **44***b* Another end portion [0154] **46** Rocker arm shaft [0155] **48** Fuel supply valve arm [0156] **48***a* Tip portion [0157] **50**, **72** Collar portion [0158] **52** Cylinder head body [0159] **53** Inclined surface (outer peripheral surface) [0160] **54** Valve seat surface [0161] **56** Valve seat member [0162] **60** First flow passage portion [0163] **62** Second flow passage portion [0164] **63** Opening end [0165] **64**, **75** Flow passage wall [0166] **65** Step [0167] **66** Lower surface [0168] **70** Outlet portion [0169] **74** Mask plate [0170] **76**, **77** Protruding portion

Claims

1. A hydrogen engine using fuel gas containing hydrogen, comprising: a cylinder; a piston movable within the cylinder; a cylinder head forming a combustion chamber with the piston, and including an intake port connected to the combustion chamber and a fuel supply port connected to the combustion chamber; an intake valve for opening and closing the intake port; a fuel supply valve for opening and closing the fuel supply port; and a valve train commonly provided for the intake valve and the fuel supply valve, and configured to open and close the intake valve and the fuel supply valve in conjunction with each other, wherein the hydrogen engine is configured such that a valve opening timing of the fuel supply valve is more retarded than a valve opening timing of the

intake valve.
2. The hydrogen engine according to claim 1, wherein the valve train includes: an intake rocker arm configured to rotate around a predetermined rotational axis and to press the intake valve; and a fuel supply valve arm configured to rotate around the rotational axis together with the intake rocker arm and to press the fuel supply valve, and wherein a maximum value of a distance between the fuel supply valve arm and the fuel supply valve in one combustion cycle of the engine is greater than a maximum value of a distance between the intake rocker arm and the intake valve in the one combustion cycle of the engine.
3. The hydrogen engine according to claim 2, wherein the distance between the fuel supply valve arm and the fuel supply valve at a valve closing timing of an exhaust valve of the engine is greater than 0.
4. The hydrogen engine according to claim 1, wherein the fuel supply valve includes: a valve stem; a valve body portion disposed on one end side of the valve stem and abuttable against a valve seat surface of the fuel supply port in an axial direction of the valve stem; and a collar portion disposed between the valve stem and the valve body portion, and located upstream of a flow of the fuel gas in an axial direction of the fuel supply valve relative to the valve seat surface of the fuel supply port in a state in which the valve body portion abuts against the valve seat surface.
5. The hydrogen engine according to claim 4, wherein $H1>0.7L$ is satisfied, where L is a lift amount of the fuel supply valve at a valve closing timing of an exhaust valve of the engine and HI is a height of the collar portion.
6. The hydrogen engine according to claim 1, wherein the fuel supply port includes: a first flow passage portion disposed along an axial direction of the fuel supply valve; a valve seat surface disposed downstream of the first flow passage portion; and a second flow passage portion disposed downstream of the valve seat surface and having a flow passage width greater than a flow passage width of the first flow passage portion, and wherein an outer peripheral surface of a valve body portion of the fuel supply valve is configured to slide on a flow passage wall of the second flow passage portion.
7. The hydrogen engine according to claim 6, wherein $H2>0.7L$ is satisfied, where L is a lift amount of the fuel supply valve at a valve closing timing of an exhaust valve of the engine and H2 is a length of the second flow passage portion in an axial direction of the fuel supply valve.
8. A hydrogen engine using fuel gas containing hydrogen, comprising: a cylinder; a piston movable within the cylinder; a cylinder head forming a combustion chamber with the piston, and including an intake port connected to the combustion chamber, a fuel supply port connected to the combustion chamber, and an exhaust port connected to the combustion chamber; an intake valve for opening and closing the intake port; a fuel supply valve for opening and closing the fuel supply port; a valve train commonly provided for the intake valve and the fuel supply valve, and configured to open and close the intake valve and the fuel supply valve in conjunction with each other; and a cover portion configured to cover at least a part of an outlet portion of the fuel supply port on a side of the exhaust port in at least a part of a valve opening period of the fuel supply valve.
9. The hydrogen engine according to claim 8, wherein the cover portion is a collar portion disposed between a valve stem of the fuel supply valve and a valve body portion, and wherein the collar portion is formed in a disk or columnar shape, is located upstream of a flow of the fuel gas in an axial direction of the fuel supply valve relative to a valve seat surface of the fuel supply port in a state in which a valve body portion of the fuel supply valve abuts against the valve seat surface, and has an outer diameter greater than an outer diameter of the valve stem.
10. The hydrogen engine according to claim 8, wherein the cylinder head includes: a cylinder head body; a valve seat member forming a valve seat surface of the fuel supply port and configured separately from the cylinder head body; and a mask plate interposed between the cylinder head body and the valve seat member, wherein the mask plate includes a protruding portion protruding

from a flow passage wall of the fuel supply port toward a valve stem of the fuel supply valve, and wherein the cover portion is the protruding portion.

11. The hydrogen engine according to claim 8, wherein the cylinder head includes: a cylinder head body; and a valve seat member forming a valve seat surface of the fuel supply port and configured separately from the cylinder head body, wherein the valve seat member includes a protruding portion protruding from a flow passage wall of the fuel supply port toward a valve stem of the fuel supply valve, and wherein the cover portion is the protruding portion.

12. The hydrogen engine according to claim 8, wherein, where a strength S of a swirling flow of intake air flowing into the combustion chamber from the intake port is a dimensionless number indicating how many times the swirling flow rotates about the combustion chamber during one rotation of the engine, an angular width OL is a width of a crank angle, which corresponds to, of one combustion cycle of the engine, a period of overlap between a valve opening period of an exhaust valve of the engine and a valve opening period of the fuel supply valve, and an angle θ is a product of the strength S of the swirling flow and the angular width OL, and where S**1** is a range on a side of the exhaust port and S**2** is a range of the angle θ from an upstream end in a rotational direction of the swirling flow in the range S**1** to an upstream side in the rotational direction of the swirling flow, in a circumferential direction around an axis of the fuel supply valve, the cover portion is disposed in a range including the range SI and the range S**2** in the circumferential direction.

13. A hydrogen engine using fuel gas containing hydrogen, comprising: a cylinder; a piston movable within the cylinder; a cylinder head forming a combustion chamber with the piston, and including an intake port connected to the combustion chamber, a fuel supply port connected to the combustion chamber, and an exhaust port connected to the combustion chamber; an intake valve for opening and closing the intake port; a fuel supply valve for opening and closing the fuel supply port; and a valve train commonly provided for the intake valve and the fuel supply valve, and configured to open and close the intake valve and the fuel supply valve in conjunction with each other, wherein a lower surface of the cylinder head is formed along a plane, and wherein a lower surface of the fuel supply valve is located upstream of a flow of the fuel gas in an axial direction of the fuel supply valve relative to the lower surface of the cylinder head, in a state in which the fuel supply valve abuts against a valve seat surface disposed in the fuel supply port.

14. The hydrogen engine according to claim 13, wherein H3>L is satisfied, where L is a lift amount of the fuel supply valve at a valve closing timing of an exhaust valve of the engine and H3 is a distance between the lower surface of the fuel supply valve and the lower surface of the cylinder head in the axial direction of the fuel supply valve in the state in which the fuel supply valve abuts against the valve seat surface disposed in the fuel supply port.