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Hydrogen power system

Abstract

A hydrogen power system includes a hydrogen engine that operates using hydrogen as an energy source, a hydrogen tank that stores liquid hydrogen, and a hydrogen pump that pumps up the liquid hydrogen from the hydrogen tank and outputs it to the hydrogen engine, A hydrogen pump, a part of which slides within the hydrogen tank, and a controller, and the controller stops driving the hydrogen pump when it is determined that the efficiency of the hydrogen pump is decreasing, and then, after a prescribed wait time has elapsed, the hydrogen pump is driven again.

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References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
12055092	12/2023	Yamamoto	N/A	F02D 41/0027
2008/0009987	12/2007	Williams et al.	N/A	N/A
2014/0322623	12/2013	Ohgami	429/427	H01M 8/04753
2021/0207552	12/2020	Nakano et al.	N/A	N/A

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
2008-031989	12/2007	JP	N/A
2020-045832	12/2019	JP	N/A

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION
(1) This application claims priority to Japanese Patent Application No. 2023-067143 filed on Apr. 17, 2023, incorporated herein by reference in its entirety.
BACKGROUND
1. Technical Field
(2) This specification discloses a hydrogen power system that includes a power device configured to operate using hydrogen as an energy source and a hydrogen tank configured to store liquid hydrogen.
2. Description of Related Art
(3) In recent years, hydrogen power systems have been known that include a power device that operates using hydrogen as an energy source and a hydrogen storage structure. For example, fuel cell electric vehicles are equipped with a hydrogen power system including: a fuel cell that generates power using hydrogen; a motor that operates on the power generated by the fuel cell; and a hydrogen tank. Hydrogen engine vehicles are equipped with a hydrogen power system that includes a hydrogen engine that operates on hydrogen and a hydrogen tank.
(4) Some of such hydrogen power systems store hydrogen in a liquid state in order to improve hydrogen storage efficiency. In this case, the hydrogen power system includes a hydrogen tank that stores liquid hydrogen and a hydrogen pump that pumps up the liquid hydrogen. A hydrogen pump typically includes a sliding member that slides inside a hydrogen tank. This sliding member is

cooled by liquid hydrogen while the hydrogen pump sucks and discharges the liquid hydrogen.

SUMMARY

(5) If the efficiency of the hydrogen pump decreases for some reason, the sliding member of the hydrogen pump may not be sufficiently cooled, and the temperature of the sliding member may rise. If the hydrogen pump continues to be driven in this state, the friction of the sliding member will increase, which may lead to degradation of the sliding member and also the hydrogen pump.

(6) Japanese Unexamined Patent Application Publication No. 2008-031989 (JP 2008-031989 A) discloses a technique for limiting the speed of a vehicle or warning a user when an abnormality is detected in a fuel pump mounted on the vehicle. However, the technique disclosed in JP 2008-031989 A cannot prevent such degradation of the hydrogen pump.

(7) The present specification therefore discloses a hydrogen power system that can effectively reduce or prevent degradation of a hydrogen pump.

(8) A hydrogen power system disclosed in this specification includes: a power device configured to operate using hydrogen as an energy source; a hydrogen tank configured to store liquid hydrogen; a hydrogen pump configured to pump up the liquid hydrogen from the hydrogen tank and output the liquid hydrogen toward the power device, and configured in such a manner that part of elements slide inside the hydrogen tank; and a controller.

(9) The controller is configured to, when the controller determines that efficiency of the hydrogen pump has decreased, stop driving the hydrogen pump, and then drive the hydrogen pump again after a prescribed wait time has elapsed.

(10) With this configuration, the hydrogen pump is cooled by the liquid hydrogen during the period in which the hydrogen pump is temporarily stopped. This reduces or prevents seizure of a sliding member and effectively reduces or prevents degradation of the hydrogen pump.

(11) In this case, the hydrogen pump may be a piston pump including a cylinder and a piston, the cylinder including a pump chamber where the liquid hydrogen flows in and out, and the piston being configured to expand and contract the pump chamber by sliding back and forth inside the cylinder.

(12) With this configuration, the piston that is the sliding member and the cylinder can reliably contact the liquid hydrogen, and the piston and the cylinder are cooled by the liquid hydrogen.

(13) The hydrogen power system may further include: a vaporizer configured to vaporize the pumped liquid hydrogen to convert the liquid hydrogen to hydrogen gas; and an intermediate chamber configured to temporarily store the hydrogen gas output from the vaporizer.

(14) Since the intermediate chamber is provided, hydrogen can continue to be supplied to the power device even when the hydrogen pump is temporarily stopped. As a result, degradation of the hydrogen pump can be effectively reduced or prevented while reducing a decrease in efficiency of the hydrogen power system itself.

(15) The controller may be configured to determine that the efficiency of the hydrogen pump has decreased when a prescribed decreased state continues for a prescribed first determination time.

(16) The decreased state may be a state where either or both of a first condition and a second condition are satisfied.

(17) The first condition may be that a drive amount of the hydrogen pump is equal to or larger than a prescribed reference drive amount.

(18) The second condition may be that a temperature of the liquid hydrogen output from the hydrogen pump is equal to or higher than a prescribed reference temperature, or that a pressure of the liquid hydrogen output from the hydrogen pump is less than a reference pressure.

(19) With this configuration, it is possible to reliably detect a decrease in efficiency of the hydrogen pump.

(20) In this case, the controller may be configured to when determination is made that the decreased state is present, increase output limitation on the power device compared to before the determination, and after driving the hydrogen pump again, gradually reducing the output limitation

on the power device according to an efficiency state of the hydrogen pump.
(21) With this configuration, the load on the hydrogen pump can be reduced according to the situation, and degradation of the hydrogen pump can be more effectively reduced or prevented.
(22) According to the technique disclosed in this specification, when it is determined that the efficiency of the hydrogen pump has decreased, the hydrogen pump is temporarily stopped. During this stop period, the hydrogen pump is cooled by the liquid hydrogen, so that degradation of the hydrogen pump can be efficiently reduced or prevented.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) Features, advantages, and technical and industrial significance of exemplary embodiments of the disclosure will be described below with reference to the accompanying drawings, in which like signs denote like elements, and wherein:
(2) FIG. **1** is a schematic diagram showing the configuration of a hydrogen power system;
(3) FIG. **2** is a cross-sectional view showing the configuration of the end of the hydrogen pump;
(4) FIG. **3** is a flowchart showing the first half of the hydrogen pump fail-safe process;
(5) FIG. **4** is a flowchart showing the second half of the hydrogen pump fail-safe process; and
(6) FIG. **5** is a flowchart showing the flow of processing for determining whether there is a decrease in efficiency.
DETAILED DESCRIPTION OF EMBODIMENTS
(7) The configuration of the hydrogen power system **10** will be described below with reference to the drawings. FIG. **1** is a schematic diagram showing the configuration of a hydrogen power system **10**. This hydrogen power system **10** stores hydrogen in a liquid state, converts hydrogen into a gas state, and supplies the hydrogen to a power device. In this example, the power device is a hydrogen engine **12**. This hydrogen power system **10** is mounted on a vehicle. The configuration of the hydrogen engine **12** is not particularly limited. In the following, the hydrogen engine **12** is a direct injection type hydrogen engine that directly injects hydrogen gas into the engine cylinder.
(8) The hydrogen power system **10** has a hydrogen tank **16** that stores liquid hydrogen. The hydrogen tank **16** stores liquid hydrogen insulated. As such hydrogen tank **16**, for example, a double-structured container can be used. In this case, the hydrogen tank **16** has an inner tank **18** and an outer tank **19** that covers the inner tank **18**, and a vacuum insulation layer is formed between the inner tank **18** and the outer tank **19**.
(9) In the hydrogen tank **16**, liquid hydrogen is kept at an extremely low temperature (e.g., below −253° C.). Further, the pressure of liquid hydrogen in the hydrogen tank **16** is approximately the same as atmospheric pressure or slightly higher than atmospheric pressure, for example, 1 MPa or less.
(10) The hydrogen tank **16** is provided with a hydrogen pump **20** that pumps up stored liquid hydrogen and sends it to the hydrogen engine **12**. This hydrogen pump **20** is a booster pump that discharges liquid hydrogen while pressurizing it. More specifically, the hydrogen pump **20** is a piston pump that includes a cylinder **22** and a piston **28** (not shown in FIG. **1**, see FIG. **2**). The end of the hydrogen pump **20** is placed within the hydrogen tank **16**.
(11) FIG. **2** is a schematic cross-sectional view of the end of the hydrogen pump **20**. As shown in FIG. **2**, a pump chamber **26** is formed at the end of the hydrogen pump **20** by a cylinder **22** and a cylinder head **24**. The piston **28** expands and contracts the pump chamber **26** by moving back and forth inside the cylinder **22**. The piston **28** moves back and forth by power output from the pump motor **23** (see FIG. **1**). Note that, as a matter of course, the circumferential surface of the piston **28** is in close contact with the inner circumferential surface of the cylinder **22**, and the piston **28** slides within the cylinder **22**.

(12) As the pump chamber **26** expands, liquid hydrogen in the hydrogen tank **16** is sucked into the pump chamber **26** via the suction port **32**. Furthermore, as the pump chamber **26** is reduced in size, the liquid hydrogen in the pump chamber **26** is pressurized and then is forced into the liquid flow path **40** through the discharge port **34**. In order to enable such suction and discharge of liquid hydrogen, check valves **36** and **38** are provided at the suction port **32** and the discharge port **34**. In this manner, by providing the hydrogen pump **20** with a pressure increasing function, the pressure resistance required for the hydrogen tank **16** can be lowered.
(13) That is, as described above, in this example, the hydrogen engine **12** is a direct injection type that injects hydrogen gas directly into the engine cylinder. The directly injected hydrogen gas is required to be at a very high pressure (for example, from 5 MPa to several tens of Mp) compared to atmospheric pressure. In order to obtain such high-pressure hydrogen gas, it is required that the pressure be sufficiently high before it is vaporized, that is, in a liquid state. Therefore, it is also possible to store liquid hydrogen at high pressure (for example, several tens of Mp) in the hydrogen tank **16**. However, in this case, the pressure resistance of the hydrogen tank **16** must be increased, leading to an increase in the cost and weight of the hydrogen tank **16**.
(14) On the other hand, in this example, the pressure of the liquid hydrogen in the hydrogen tank **16** is set to approximately the same pressure or slightly higher than atmospheric pressure, and when the liquid hydrogen is vaporized, the hydrogen pump **20** is used to sufficiently increase the pressure of only the necessary amount. Then I take it out. With this configuration, hydrogen gas at a sufficiently high pressure can be obtained while keeping the pressure resistance of the hydrogen tank **16** low. In addition, by lowering the required pressure resistance, the cost required for the hydrogen tank **16** can be reduced. Furthermore, by lowering the required pressure resistance, the weight of the hydrogen tank **16** can be reduced. Furthermore, by lowering the required pressure resistance, it is possible to adopt a shape other than a spherical shape or a barrel shape as the shape of the hydrogen tank **16**, and the degree of freedom in the shape of the hydrogen tank **16** is improved.
(15) This will be explained with reference to FIG. **1** again. The pressure sensor **44** and the temperature sensor **42** detect the pressure and temperature of liquid hydrogen discharged from the hydrogen pump **20**. Hereinafter, the pressure detected by the pressure sensor **44** will be referred to as “discharge hydrogen pressure PH”, and the temperature detected by the temperature sensor **42** will be referred to as “discharge hydrogen temperature TH”. When the efficiency of the hydrogen pump **20** decreases, the discharge hydrogen pressure PH tends to decrease, and the discharge hydrogen temperature TH tends to increase.
(16) Liquid hydrogen discharged from the hydrogen pump **20** is supplied to the hydrogen engine **12** through a liquid flow path **40** and a gas flow path **46**. The liquid flow path **40** is a flow path that guides liquid hydrogen discharged from the hydrogen pump **20** to the vaporizer **48**. The vaporizer **48** is a heat exchanger that converts liquid hydrogen into hydrogen gas by exchanging heat between the liquid hydrogen and a refrigerant. Hydrogen gas generated in the vaporizer **48** is output to the gas flow path **46**.
(17) The vaporizer **48** exchanges heat between liquid hydrogen and a refrigerant, and vaporizes the liquid hydrogen. Refrigerant pump **52** circulates refrigerant between vaporizer **48** and heat source **50**. Note that the refrigerant is not particularly limited, and may be a gas such as helium or a liquid such as water.
(18) The gas flow path **46** is a flow path that guides hydrogen gas from the vaporizer **48** to the injector **14**. An intermediate chamber **54** is connected to the gas flow path **46** via an inflow channel **56** and an outflow channel **60**. The intermediate chamber **54** is a container that is disposed between the hydrogen tank **16** and the hydrogen engine **12** and temporarily stores hydrogen gas. By storing a certain amount of hydrogen gas in the intermediate chamber **54**, even if pumping of liquid hydrogen by the hydrogen pump **20** is temporarily suppressed or interrupted, hydrogen gas can be stably supplied to the hydrogen engine **12**. can continue to be supplied.

(19) The inflow channel **56** is provided with a check valve **58** that prohibits flow from the intermediate chamber **54** toward the gas flow path **46**. Further, the outflow channel **60** is provided with a shut valve **62**. In principle, the shut valve **62** is opened while the hydrogen engine **12** is being driven. Further, the inflow channel **56** is located upstream of the outflow channel **60**. Therefore, when the pressure in the gas flow path **46** is higher than the internal pressure in the intermediate chamber **54**, the check valve **58** is opened and hydrogen gas flows into the intermediate chamber **54**. On the other hand, when the internal pressure of the intermediate chamber **54** is higher than the pressure of the gas flow path **46**, the hydrogen gas stored in the intermediate chamber **54** is supplied to the gas flow path **46** through the outflow channel **60**.
(20) A supply pressure reducing valve **64** is provided downstream of the outflow channel **60**. The supply pressure reducing valve **64** reduces the pressure of hydrogen gas to a pressure suitable for the hydrogen engine **12**. The reduced pressure hydrogen gas is supplied to the hydrogen engine **12** via the injector **14**. The flow rate of hydrogen gas supplied to the hydrogen engine **12** is detected by a flow meter **66**.
(21) Controller **70** controls the operation of hydrogen power system **10**. Controller **70** is physically a computer that includes a processor **72** and memory **74**. The term “computer” also includes microcontrollers that incorporate a computer system into a single integrated circuit. Further, the controller **70** is not limited to one computer, but may be configured by combining a plurality of physically separated computers. The controller **70** controls the driving of a plurality of valves and pumps provided in the hydrogen power system **10** based on values detected by various sensors.
(22) Specifically, the controller **70** controls the flow rate of hydrogen gas supplied to the hydrogen engine **12** in response to a request from an engine control unit (not shown). Further, the controller **70** executes fail-safe processing for the hydrogen pump **20**. The fail-safe processing of this hydrogen pump **20** will be explained in detail below.
(23) As described above, some elements (specifically, the piston **28**) of the hydrogen pump **20** slide as it is driven. The piston **28** and cylinder **22** involved in the sliding movement are normally cooled by liquid hydrogen flowing into the pump chamber **26**. However, if the efficiency of the hydrogen pump **20** decreases for some reason, the piston **28** and cylinder **22** will not be sufficiently cooled by liquid hydrogen. As a result, the clearance between the piston **28** and the cylinder **22** may become smaller, and the temperatures of both may rise. If the hydrogen pump **20** continues to be driven in this state, the temperatures of the piston **28** and cylinder **22** will further rise, and in some cases, the piston **28** will seize up on the cylinder **22**, causing degradation or damage to the hydrogen pump **20**.
(24) In order to suppress such degradation of the hydrogen pump **20**, the controller **70** monitors the state of the hydrogen pump **20**, and executes fail-safe processing to temporarily stop driving the hydrogen pump **20**, if necessary. FIGS. **3** and **4** are flowchart showing the flow of failsafe processing. This failsafe process is repeatedly executed while the hydrogen engine **12** is being driven.
(25) In the fail-safe process, the controller **70** monitors whether the hydrogen pump **20** is in a prescribed decreased state. Here, the “decreased state” is a state that satisfies both the first condition and the second condition described below. The first condition is that the drive amount of the hydrogen pump **20** (hereinafter referred to as “pump drive amount DA”) is equal to or greater than a prescribed reference drive amount DAst. As a parameter representing the pump drive amount DA, for example, the most recent power consumption of the hydrogen pump **20** or the most recent number of discharges of the hydrogen pump **20** can be adopted. Note that the reference drive amount DAst may be a fixed value that does not change regardless of the situation, or may be a variable value that changes depending on the situation. For example, the reference drive amount DAst may be a variable value that changes depending on the target discharge flow rate of the hydrogen pump **20**.
(26) The second condition is that the discharge hydrogen temperature TH is equal to or higher than

the prescribed reference temperature THst, or that the discharge hydrogen pressure PH is lower than the prescribed reference pressure PHst. Here, the reference temperature THst and the reference pressure PHst may also be fixed values that do not change regardless of the situation, or may be variable values that change depending on the situation.

(27) If both the first condition and the second condition are satisfied, the controller **70** determines that the hydrogen pump **20** is in a decreased state. FIG. **5** is a flowchart showing the flow of determining whether the hydrogen pump **20** is in the decreased state. As shown in FIG. **5**, the controller **70** compares the pump drive amount DA and the reference drive amount DAst (S**50**), and if DA<DAst (No in S**50**), determines that the pump drive amount DA is not in a decreased state (S**58**). On the other hand, if DA≥DAst (Yes in S**50**), the controller **70** compares the discharge hydrogen temperature TH and the reference temperature THst (S**52**). As a result of the comparison, if TH≥THst (Yes in S**52**), the controller **70** determines that the hydrogen pump **20** is in the decreased state (S**56**). On the other hand, if TH<THst (No in S**52**), the controller **70** compares the discharge hydrogen pressure PH and the reference pressure PHst (S**54**). As a result of the comparison, if PH≥PHst (No in S**54**), the controller **70** determines that the hydrogen pump **20** is not in the decreased state (S**58**). On the other hand, if PH<PHst (Yes in S**54**), the controller **70** determines that the hydrogen pump **20** is in the decreased state (S**56**).

(28) The explanation will be given again with reference to FIG. **3**. When the hydrogen pump **20** is not in the decreased state (No in S**10**), the controller **70** continues to monitor the state of the hydrogen pump **20**. On the other hand, when the hydrogen pump **20** is in the decreased state (Yes in S**10**), the controller **70** increases the output limitation on the hydrogen engine **12** (S**12**). That is, normally, an upper limit value, that is, an output limit value is set for the output value of the hydrogen engine **12**. An engine controller (not shown) controls the drive of the hydrogen engine **12** so that the output from the hydrogen engine **12** does not exceed this output limit value. Usually, a predetermined standard limit value LMst is set as this output limit value.

(29) When the hydrogen pump **20** is in the decreased state, the controller **70** sets the output limit value of the hydrogen engine **12** to the regulation limit value LMa, which is lower than the standard limit value LMst. When the output limit value of the hydrogen engine **12** is lowered, the demand for pumping up liquid hydrogen is also reduced accordingly, so that the load on the hydrogen engine **12** is reduced.

(30) The controller **70** continues to monitor whether the hydrogen pump **20** is in the decreased state while the load on the hydrogen engine **12** is reduced (S**14**). During the monitoring process, when the hydrogen engine **12** is no longer in the decreased state (No in S**14**), the controller **70** completely reduces the output limitation on the hydrogen engine **12** (S**16**). That is, the controller **70** changes the output limit value of the hydrogen engine **12** from the regulation limit value LMa to the standard limit value LMst, and then returns to S**10**.

(31) On the other hand, when the hydrogen engine **12** remains in the decreased state (Yes in S**14**), the controller **70** compares the elapsed time since the hydrogen engine **12** went into the decreased state with a prescribed first determination time tf (S**18**). The first determination time tf is, for example, about 2 to 5 seconds, although it is not particularly limited. When the decreased state continues for the first determination time tf (Yes in S**18**), the controller **70** determines that the efficiency of the hydrogen pump **20** has decreased. In this case, the controller **70** stops driving the hydrogen pump **20** (S**20**). As a result, the sliding movement of the piston **28** of the hydrogen engine **12** is stopped. During this stop period, the piston **28** and cylinder **22** are cooled by the liquid hydrogen present around them. As a result, the clearance between the piston **28** and the cylinder **22** increases, and the efficiency of the hydrogen pump **20** is restored.

(32) Note that when the hydrogen pump **20** stops driving, naturally the supply of hydrogen from the hydrogen tank **16** to the liquid flow path **40** is interrupted. However, in this example, since a certain amount of hydrogen gas is stored in the intermediate chamber **54**, even if the hydrogen supply from the hydrogen tank **16** is temporarily interrupted, the hydrogen gas supply to the

hydrogen engine **12** is continued. can. That is, in this example, while the hydrogen pump **20** is not being driven, the hydrogen engine **12** continues to be driven, although the output limitation is increased.
(33) After the hydrogen pump **20** is stopped, the controller **70** restarts driving the hydrogen pump **20** (S**24**) when the prescribed wait time tw has elapsed (S**22**). Note that the wait time tw is not particularly limited, but for example, the wait time tw is a value larger than the first determination time tf, for example, from 5 seconds to 15 seconds. Further, the wait time tw may be a fixed value that is constant regardless of the situation, or may be a variable value that changes depending on the situation. For example, the wait time tw increases as the pump drive amount DA, detected immediately before stopping the hydrogen pump **20**, or as the discharge hydrogen temperature TH increases, or as the discharge hydrogen pressure PH decreases. It may be a variable value.
(34) When the hydrogen pump **20** is restarted, the controller **70** gradually reduces the output limitation on the hydrogen engine **12** (S**26** to S**38** in FIG. **4**). Specifically, the controller **70** detects the state of the hydrogen pump **20** when the prescribed second determination time ts has elapsed (Yes in S**26**) after the hydrogen pump **20** resumes driving. If the hydrogen pump **20** is in the decreased state at this timing (Yes in S**28**), the process returns to S**20** (see FIG. **3**) and the hydrogen pump **20** is stopped again. Note that the second determination time ts is not particularly limited, and is, for example, from 2 seconds to 7 seconds.
(35) On the other hand, in S**28**, when the hydrogen pump **20** is not in the decreased state (No in S**28**), the controller **70** temporarily reduces the output limitation on the hydrogen engine **12** (S**30**). In the case of provisional relaxation, the controller **70** sets the output limit value to an intermediate limit value LMb, which is smaller than the standard limit value LMst and larger than the regulation limit value LMa.
(36) Further, the controller **70** continues driving the hydrogen pump **20** for the second determination time ts with the output limitation temporarily reduced (S**32**). Then, at the timing when the second determination time ts has elapsed (Yes in S**32**), the controller **70** determines the state of the hydrogen pump **20** again (S**34**). As a result of the determination, when the hydrogen pump **20** is in the decreased state (Yes in S**34**), the controller **70** increases the output limitation on the hydrogen engine **12** (S**36**), and then returns to S**26**. On the other hand, when the controller **70** determines in S**34** that the hydrogen engine **12** is not in the decreased state (No in S**34**), it completely reduces the output limitation on the hydrogen engine **12** (S**38**). That is, the output limit value of the hydrogen engine **12** is changed from the intermediate limit value LMb to the standard limit value LMst. Thereafter, the controller **70** repeats the processes from S**10** to S**38** until an instruction is given to stop the operation of the hydrogen power system **10**.
(37) As is clear from the above explanation, in this example, when the efficiency of the hydrogen engine **12** has decreased, the driving of the hydrogen pump **20** is temporarily stopped. During this temporary stop period, the area around the sliding member of the hydrogen pump **20** is cooled by liquid hydrogen, making it easier to restore the efficiency of the hydrogen pump **20**. As a result, degradation of the hydrogen pump **20** can be effectively reduced or prevented.
(38) Further, in this example, since the intermediate chamber **54** for temporarily storing hydrogen gas is provided, even if the hydrogen engine **12** is temporarily stopped, the hydrogen engine **12** can be continuously driven. In other words, according to this example, degradation of the hydrogen pump **20** can be reduced or prevented while reducing a decrease in efficiency of the hydrogen power system **10**.
(39) Furthermore, in this example, the output limitation on the hydrogen engine **12** is changed depending on the state of the hydrogen pump **20**. This reduces or eliminates the possibility of an excessive load being applied to the hydrogen pump **20**, so that degradation of the hydrogen pump **20** can be more effectively reduced or prevented.
(40) Note that the configurations described so far are only examples, and other configurations may be changed as appropriate as long as the configuration according to claim **1** is provided. For

example, in the above description, the output limitation on the hydrogen engine **12** is changed depending on the state of the hydrogen pump **20**. However, when the drive of the hydrogen pump **20** is temporarily stopped depending on the state of the hydrogen pump **20**, the output limitation on the hydrogen engine **12** does not need to be changed. Further, the conditions for determining that the efficiency of the hydrogen pump **20** has decreased may also be changed as appropriate. For example, in the above description, when a state in which both the first condition and the second condition are satisfied continues for the wait time tw, the controller **70** determines that the efficiency of the hydrogen pump **20** has decreased, and the hydrogen pump **20** is temporarily stopped. However, if only one of the first condition and the second condition continues to be satisfied, it may be determined that the efficiency of the hydrogen pump **20** has decreased. Furthermore, it may be determined whether the efficiency of the hydrogen pump **20** has decreased based on another condition.
(41) Furthermore, in the above description, the hydrogen engine **12** is illustrated as the power device. However, the power device may be any other device as long as it outputs power using hydrogen as an energy source. For example, the power device may be a device that includes a fuel cell that generates power using hydrogen and a motor that outputs motive power using the electric power generated by the fuel cell. Furthermore, in the above description, if the efficiency of the hydrogen pump **20** has decreased, the driving of the hydrogen pump **20** is stopped as many times as necessary. However, if the drive of the hydrogen pump **20** frequently stops, the operation of the hydrogen power system **10** itself may be stopped after giving a warning to the user.

Claims

1. A hydrogen power system, comprising: a power device configured to operate using hydrogen as an energy source; a hydrogen tank configured to store liquid hydrogen; a hydrogen pump configured to pump up the liquid hydrogen from the hydrogen tank and output the liquid hydrogen toward the power device, and configured in such a manner that part of elements slide inside the hydrogen tank; and a controller, wherein the controller is configured to, when the controller determines that efficiency of the hydrogen pump has decreased, stop driving the hydrogen pump, and then drive the hydrogen pump again after a prescribed wait time has elapsed.
2. The hydrogen power system according to claim 1, wherein the hydrogen pump is a piston pump including a cylinder and a piston, the cylinder including a pump chamber where the liquid hydrogen flows in and out, and the piston being configured to expand and contract the pump chamber by sliding back and forth inside the cylinder.
3. The hydrogen power system according to claim 1, further comprising: a vaporizer configured to vaporize the pumped liquid hydrogen to convert the liquid hydrogen to hydrogen gas; and an intermediate chamber configured to temporarily store the hydrogen gas output from the vaporizer.
4. The hydrogen power system according to claim 1, wherein: the controller is configured to determine that the efficiency of the hydrogen pump has decreased when a prescribed decreased state continues for a prescribed first determination time; the decreased state is a state where either or both of a first condition and a second condition are satisfied; the first condition is that a drive amount of the hydrogen pump is equal to or larger than a prescribed reference drive amount; and the second condition is that a temperature of the liquid hydrogen output from the hydrogen pump is equal to or higher than a prescribed reference temperature, or that a pressure of the liquid hydrogen output from the hydrogen pump is less than a reference pressure.
5. The hydrogen power system according to claim 4, wherein the controller is configured to when determination is made that the decreased state is present, increase output limitation on the power device compared to before the determination, and after driving the hydrogen pump again, gradually

reducing the output limitation on the power device according to an efficiency state of the hydrogen pump.