

DESCRIPTION

Title of Invention: GAS ENGINE CONTROL METHOD AND GAS ENGINE SYSTEM

Technical Field

[0001] The present invention relates to a method of controlling a gas engine connected to a turbocharger. The present invention also relates to a gas engine system including a turbocharger and a gas engine.

Background Art

[0002] Gas engines used as main engines (internal combustion engines for propulsion) of ships are conventionally known. Such gas engines are disclosed in, for example, PTLs 1 and 2.

[0003] The gas engine disclosed in PTL 1 is a gas engine equipped with a turbocharger. A main chamber of the gas engine is connected to a compressor of the turbocharger through an intake passage and also connected to a turbine of the turbocharger through an exhaust passage. A fuel injection valve configured to inject fuel gas to air discharged from the compressor is provided at the intake passage. An air-fuel mixture constituted by the air and the fuel gas and having an ignitable excess air ratio (also called an air-fuel ratio) is supplied to a pre-chamber of the gas engine, and a lean air-fuel mixture constituted by the air and the fuel gas is supplied to the main chamber of the gas engine. When the air-fuel mixture in the pre-chamber is ignited by an ignition device to be combusted, a burnt gas in the pre-chamber jets out to the main chamber by volume expansion due to the combustion of the mixture, and a high-temperature jet-out flow jetting out to the main chamber ignites the lean air-fuel mixture in the main chamber. Thus, flame propagation to the main chamber occurs.

[0004] As shown in FIG. 12, in the gas engines, it is generally known that a knocking region and a misfire region exist based on a relationship between the excess air ratio and brake mean effective pressure (BMEP). In order to obtain high output in lean burn, it is important to control the excess air ratio between the knocking region and the misfire region as shown by a range X in FIG. 12. Therefore, according to the gas engine in steady operation, a fuel injection amount and a turbocharging amount are controlled such that the excess air ratio falls within a range between the knocking region and the misfire region.

[0005] When a load of the gas engine steeply increases, and the fuel gas is increased in accordance with this steep increase in the load of the gas engine, the air supplied to the gas engine also needs to be increased. If the air is not increased, an operating point in the range X moves to the left, and a knocking occurrence ratio exceeds a knocking limit. To be specific, in order to obtain output that follows the steep change in the load without causing abnormal

combustion, the air needs to be increased or decreased at a rate corresponding to a rate of increase or decrease of the fuel gas. However, in the gas engine connected to the turbocharger, even when the fuel gas is increased, the air does not increase immediately due to a turbo lag. Therefore, the fuel gas cannot be increased quickly.

[0006] According to the gas engine of PTL 1, when the load increases during the steady operation, the gas engine starts a load increase operation. When the degree of the increase in the load becomes relatively large during the load increase operation, an ignition timing is retarded, and an actual fuel injection amount is gradually increased. With this, a room for the excess air ratio up to the knocking limit increases, and the actual fuel injection amount can be increased significantly. Therefore, the fuel gas can be increased quickly.

[0007] According to a main engine of a ship that sails on the sea or a river, the amount of fuel supplied to the main engine is typically controlled such that the rotational frequency of a propeller shaft coupled to a propulsion propeller or the rotational frequency of an engine directly coupled to the propeller shaft becomes a given target rotational frequency. The rotational frequency of the propulsion propeller of the ship tends to change in a short term by tidal currents, waves, a rudder angle of the ship, and the like.

[0008] PTL 2 proposes a technology by which a required amount of fuel can be supplied to the engine in accordance with a short-term change in the rotational frequency of the propulsion propeller. More specifically, according to the engine disclosed in PTL 2, a future predicted ship speed of the ship is calculated based on information of a current rudder angle given to the ship, information of a current rotational frequency of the propeller shaft, and information of a current ship speed of the ship, and a predicted torque is calculated based on the predicted ship speed. Then, a predicted amount of fuel supplied is calculated based on the predicted torque, and pressure of the fuel supplied to the engine by a compressor is controlled based on the predicted amount of fuel supplied.

Citation List

Patent Literature

[0009] PTL 1: Japanese Patent No. 6049921

PTL 2: Japanese Laid-Open Patent Application Publication No. 2016-205270

Summary of Invention

Technical Problem

[0010] Typically, when an engine output cannot follow the increase in the load, and

therefore, the rotational frequency of the engine decreases, a controller of the main engine of the ship detects the increase in the load and outputs a command of increasing the fuel gas in accordance with the increase in the load. However, before the actual increase in the load is detected as above, a future increase in the load can be predicted in some cases. For example, when a rudder angle operation amount of the ship has changed, a time lag may be generated between when the rudder angle operation amount has changed and when the load actually changes, although it depends on various conditions, such as the changed rudder angle, the ship speed, ocean currents, and ocean waves.

[0011] In PTL 1, the ignition timing is retarded, and the actual fuel injection amount is gradually increased. With this, the fuel gas can be increased quickly. However, when the future increase in the load can be predicted in advance as described above, the turbocharging amount is increased before the actual increase in the load. With this, the fuel gas can be more quickly increased at the time of the increase in the load.

[0012] An object of the present invention is to, when a load of a gas engine connected to a turbocharger steeply increases, quickly increase an injection amount of a fuel gas in response to the steep increase in the load, and with this, improve load responsiveness (followability of actual output with respect to required output).

Solution to Problem

[0013] A gas engine control method according to one aspect of the present invention is a method of controlling a gas engine connected to a turbocharger including a compressor and a turbine and includes: predicting an increase in a load of the gas engine before the load of the gas engine actually increases; when a degree of the predicted increase in the load exceeds a predetermined threshold, increasing a rotational frequency of the turbocharger while suppressing an increase in turbocharging pressure; and when the increase in the load of the gas engine is detected, increasing the turbocharging pressure and a fuel injection amount.

It should be noted that as an index of the degree of the increase in the load of the gas engine, at least one of a difference between a target rotational frequency and actual rotational frequency of the gas engine, a difference between a target output and required output of the gas engine, a difference between a required fuel injection amount and actual fuel injection amount of the gas engine, and a difference between target turbocharging pressure and actual turbocharging pressure of the gas engine may be used.

[0014] Moreover, a gas engine system according to one aspect of the present invention includes: a turbocharger including a compressor and a turbine; a gas engine connected to the

compressor through an intake passage and also connected to the turbine through an exhaust passage; a fuel injection mechanism configured to inject fuel gas into air to be supplied to the gas engine through the intake passage; and a controller configured to control the turbocharger, the gas engine, and the fuel injection mechanism. The controller predicts an increase in a load of the gas engine before the load of the gas engine actually increases. When a degree of the predicted increase in the load exceeds a predetermined threshold, the controller performs processing of increasing a rotational frequency of the turbocharger while suppressing an increase in turbocharging pressure. When the increase in the load of the gas engine is detected in the steady operation, the controller performs processing of increasing the turbocharging pressure and a fuel injection amount.

[0015] According to the above gas engine control method and the above gas engine system, the increase in the load of the gas engine is predicted before the load of the gas engine actually increases, and the rotational frequency of the turbocharger can be increased before the increase in the load. Therefore, when the load of the gas engine has actually increased, the rotational frequency of the turbocharger has already been increased, so that the turbocharging pressure can be immediately increased, and the fuel injection amount can be quickly increased such that the excess air ratio falls within an appropriate range. With this, load responsiveness (followability of the actual output with respect to the required output) of gas the engine can be improved.

[0016] The above gas engine system may be configured such that: an intake blow off valve configured to discharge gas from the intake passage is provided at the intake passage; in the processing of increasing the rotational frequency of the turbocharger, the controller increases an opening degree of the intake blow off valve so as to suppress the increase in the turbocharging pressure, the increase in the turbocharging pressure being caused due to the increase in the rotational frequency of the turbocharger; and in the processing of increasing the turbocharging pressure, the controller controls the intake blow off valve such that the opening degree of the intake blow off valve is reduced, or the intake blow off valve is closed.

[0017] With this, the rotational frequency of the turbocharger can be increased while suppressing the increase in the turbocharging pressure. Moreover, the turbocharging pressure can be quickly increased in a state where the rotational frequency of the turbocharger is increased while suppressing the increase in the turbocharging pressure.

[0018] In the above gas engine control method and the above gas engine system, the gas engine may be a main engine of a ship, and the predicted increase in the load of the gas engine may be an increase in the load of the gas engine when a rudder angle changes in accordance with a change in a rudder angle operation amount of the ship.

[0019] Moreover, in the above gas engine control method and the above gas engine system, the gas engine may be a main engine of a ship including a turning thruster, and the predicted increase in the load of the gas engine may be an increase in the load of the gas engine after the turning thruster has started turning in accordance with a change in a rudder angle operation amount of the ship.

[0020] When the rudder angle operation amount of the ship changes as above, a time lag may be generated between when the rudder angle operation amount changes and when the load of the gas engine actually increases. By utilizing this time lag, the rotational frequency of the turbocharger can be increased in preparation for the actual increase in the load.

[0021] In the above gas engine control method, increasing the rotational frequency of the turbocharger may include at least one of: increasing an excess air ratio of an air-fuel mixture to be supplied to a combustion chamber of the gas engine, the air-fuel mixture being constituted by fuel gas and air; retarding an ignition timing; retarding a pilot fuel injection timing; performing jet-assist of rotation of the compressor; reducing an opening area of a nozzle of the turbine; and reducing gas discharged from an exhaust passage of the combustion chamber to an outside of the gas engine.

[0022] In the above gas engine system, an intake blow off valve configured to discharge gas from the intake passage may be provided at the intake passage, and the processing of increasing the rotational frequency of the turbocharger may be processing of operating the intake blow off valve such that an excess air ratio of an air-fuel mixture to be supplied to a combustion chamber of the gas engine is increased, the air-fuel mixture being constituted by the fuel gas and the air.

[0023] Or, in the above gas engine system, the gas engine may include an ignition device configured to ignite an air-fuel mixture constituted by the fuel gas and the air, and the processing of increasing the rotational frequency of the turbocharger may be processing of operating the ignition device such that an ignition timing or a pilot fuel injection timing is retarded.

[0024] Or, in the above gas engine system, a nozzle and a jet assist valve may be provided at the compressor, the nozzle being configured to supply high-pressure air, supplied from a high-pressure air source, to the compressor, the jet assist valve being provided between the high-pressure air source and the nozzle, and the processing of increasing the rotational frequency of the turbocharger may be processing of switching the jet assist valve such that jet-assist of rotation of the compressor is performed by the high-pressure air jetting out from the nozzle.

[0025] Or, in the above gas engine system, the turbocharger may include a nozzle configured to spray exhaust gas to a turbine impeller, an opening degree of the nozzle being variable, and the processing of increasing the rotational frequency of the turbocharger may be

processing of reducing an opening area of the nozzle.

[0026] Or, in the above gas engine system, an exhaust wastegate valve configured to discharge gas from the exhaust passage may be provided at the exhaust passage, and the processing of increasing the rotational frequency of the turbocharger may be processing of reducing an opening degree of the exhaust wastegate valve.

[0027] According to the above processing performed in order to increase the rotational frequency of the turbocharger, the rotational frequency of the turbocharger can be increased while suppressing influences on the steady operation of the gas engine.

Advantageous Effects of Invention

[0028] According to the present invention, when the load of the gas engine connected to the turbocharger steeply increases, the injection amount of the fuel gas can be quickly increased in response to the steep increase in the load of the gas engine. With this, the improvement of the load responsiveness of the gas engine is expected.

Brief Description of Drawings

[0029] FIG. 1 is a diagram showing one example of a ship on which a gas engine according to the present embodiment is mounted.

FIG. 2 is an enlarged view of a marine propulsion device of the ship shown in FIG. 1.

FIG. 3 is a schematic configuration diagram of a gas engine system.

FIG. 4 is a sectional view of major components of the gas engine.

FIG. 5 is a diagram showing the configuration of a control system for the gas engine system and the marine propulsion device.

FIG. 6 is a graph showing relationships between an ignition timing and a knocking occurrence ratio for respective air ratios at a specific rotational frequency and a specific fuel injection amount.

FIG. 7 is a flow chart of a load increase operation.

FIG. 8A is a graph showing a time-lapse change of a required fuel injection amount Q and a time-lapse change of an actual fuel injection amount q when the degree of an increase in a load is relatively small.

FIG. 8B is a graph showing a time-lapse change of the required fuel injection amount Q and a time-lapse change of the actual fuel injection amount q when the degree of the increase in the load is relatively large.

FIG. 9A is an excess air ratio first lower limit map in which first lower limits of an excess air ratio are set in accordance with the actual fuel injection amount q and an actual rotational frequency N .

FIG. 9B is an excess air ratio second lower limit map in which second lower limits of the excess air ratio are set in accordance with the actual fuel injection amount q and the actual rotational frequency N .

FIG. 10 shows a graph of a time-lapse change of a turning angle when a rudder angle operation amount has changed and a graph of a time-lapse change of the load of the gas engine when the rudder angle operation amount has changed.

FIG. 11 is a flow chart of load increase preparation processing.

FIG. 12 is a graph showing a knocking region and a misfire region in the gas engine. In FIG. 12, a horizontal axis denotes an air-fuel ratio, and a vertical axis denotes brake mean effective pressure.

Description of Embodiments

[0030] Next, an embodiment of the present invention will be described with reference to the drawings. FIG. 1 is a diagram showing one example of a ship 11 on which a gas engine 2 according to the present embodiment is mounted. FIG. 2 is an enlarged view of a marine propulsion device 8 of the ship 11 shown in FIG. 1. The ship 11 shown in FIG. 1 is a tugboat including: the gas engine 2 as a main engine; and a turning thruster (azimuth thruster) as the marine propulsion device 8. It should be noted that the ship 11 to which the present invention is applied is not limited to the present embodiment.

[0031] Configuration of Marine Propulsion Device 8

The marine propulsion device 8 includes an upper gear box 81, a turning tube 82, a propulsion blade (propeller) 83, a drive mechanism for the propulsion blade 83, and a turning driving device 84. The upper gear box 81 is fixed to an upper portion of a platform 80 provided at a bottom portion of a hull. The turning tube 82 is supported by a lower portion of the platform 80 so as to be turnable. The propulsion blade 83 is provided at an end portion of the turning tube 82. The drive mechanism for the propulsion blade 83 is configured in the upper gear box 81 and the turning tube 82. The turning driving device 84 makes the turning tube 82 turn.

[0032] A clutch 85 and a gear group are provided in the upper gear box 81. The clutch 85 switches between force transmission and force cutoff, and the gear group changes a force transmission direction. Driving force of the gas engine 2 as the main engine is transmitted

through an intermediate shaft, a joint, and the like to an input shaft 86 which inputs force to the upper gear box 81.

[0033] A horizontal shaft 87 is arranged in the upper gear box 81 so as to be lined up with the input shaft 86 in series such that a center axis of the horizontal shaft 87 and a center axis of the the input shaft 86 are located on the same straight line. The clutch 85 is provided between the horizontal shaft 87 and the input shaft 86. The clutch 85 switches between the force transmission and the force cutoff between the input shaft 86 and the horizontal shaft 87.

[0034] An upper bevel pinion gear 88 that rotates integrally with the horizontal shaft 87 is provided in the upper gear box 81. The upper bevel pinion gear 88 meshes with an upper bevel wheel gear 89. The upper bevel wheel gear 89 is provided at an upper end portion of a vertical shaft 90 arranged so as to be substantially perpendicular to the horizontal shaft 87 and substantially vertical to the platform 80.

[0035] The vertical shaft 90 is inserted into the turning tube 82 and supported by the turning tube 82 so as to be turnable. A lower bevel pinion gear 91 is provided at a lower end portion of the vertical shaft 90 in the turning tube 82. A propeller shaft 93 is inserted into a lower portion of the turning tube 82. A lower bevel wheel gear 92 that meshes with the lower bevel pinion gear 91 is provided at the propeller shaft 93. The propeller shaft 93 is arranged so as to be substantially perpendicular to the vertical shaft 90. The propulsion blade 83 is provided at an end portion of the propeller shaft 93, the end portion projecting from the turning tube 82. A cylindrical duct 94 having a wing-shaped section is provided around the propulsion blade 83.

[0036] An upper end portion of the turning tube 82 is suspended from the platform 80 through a turning bearing (not shown) such that the turning tube 82 is turnable. A turning gear 95 is formed at an inner peripheral edge of the upper end portion of the turning tube 82. The turning gear 95 meshes with a driving gear 97 configured to be rotated by rotational output of a turning motor 96 fixed to the platform 80. The turning motor 96 may be a hydraulic motor or an electric motor. A turning angle (turning position) of the turning tube 82 is detected by a turning angle sensor 66.

[0037] In the marine propulsion device 8 configured as above, the driving force of the gas engine 2 is transmitted from the input shaft 86 through the clutch 85 to the horizontal shaft 87, and thus, the horizontal shaft 87 rotates. The rotation of the horizontal shaft 87 is transmitted through the upper bevel gear mechanisms 88 and 89 to the vertical shaft 90. Moreover, the rotation is transmitted from the vertical shaft 90 through the lower bevel gear mechanisms 91 and 92 to the propeller shaft 93. Thus, the propulsion blade 83 rotates integrally with the propeller shaft 93. When the propulsion blade 83 rotates, sea water sucked into the duct 94 jets

out, and this jet-out flow propels the hull.

[0038] In the marine propulsion device 8 configured as above, the turning motor 96 rotates the driving gear 97, and this can turn the turning tube 82 at 360° in a horizontal direction. By turning the turning tube 82 to an arbitrary position, the hull can be steered in an arbitrary direction.

[0039] **Configuration of Gas Engine System 1**

FIG. 3 is a schematic configuration diagram of a gas engine system 1. The gas engine system 1 shown in FIG. 3 includes the gas engine 2, a turbocharger 3, and a controller 7 (see FIG. 4). In the present embodiment, the propeller shaft 93 to which the propulsion blade 83 is attached is directly driven by the gas engine 2. However, the propeller shaft 93 may be indirectly driven by the gas engine 2 through a motor and an electric power generator (both not shown).

[0040] The gas engine 2 may be a gas single-fuel-combustion engine configured to combust only fuel gas (natural gas, for example). It should be noted that the gas engine 2 may be a binary fuel engine configured to combust one or both of fuel gas and fuel oil depending on situations. Moreover, in the present embodiment, the gas engine 2 is a four-stroke engine. However, the gas engine 2 may be a two-stroke engine.

[0041] FIG. 4 is a sectional view of major components of the gas engine 2. The gas engine 2 includes a plurality of cylinders 21 (in FIG. 4, only one cylinder 21 is shown). A piston 22 is provided in each cylinder 21 so as to be able to reciprocate. A combustion chamber 20 is formed by the cylinder 21 and the piston 22. The piston 22 is coupled to a crank shaft (not shown) by a connecting rod (not shown).

[0042] When the piston 22 reciprocates twice in each cylinder 21, one cycle (intake, compression, expansion, and exhaust) of the gas engine 2 is performed. A phase angle (0° to 720°) of the gas engine 2 during one cycle in the cylinder 21 is detected by a phase angle detector 63. As the phase angle, a rotation angle (crank angle) of the crank shaft, the position of the piston 22, or the like may be used. For example, the phase angle detector 63 is an electromagnetic pickup, a proximity switch, or a rotary encoder. The phase angle detector 63 also detects an actual rotational frequency N of the gas engine 2.

[0043] Referring back to FIG. 3, the turbocharger 3 includes a compressor 31 and a turbine 32. The gas engine 2 is connected to the compressor 31 through an intake passage 41 and also connected to the turbine 32 through an exhaust passage 42. The intake passage 41 introduces the air, compressed by the compressor 31, to each cylinder 21. The exhaust passage 42

introduces exhaust gas, generated after the combustion, from each cylinder 21 to the turbine 32. An intake blow off valve 48 is provided at the intake passage 41. The intake blow off valve 48 discharges gas from the intake passage 41 to release pressure in the intake passage 41. An exhaust wastegate valve 49 is provided at the exhaust passage 42. The exhaust wastegate valve 49 divides a part of the gas in the exhaust passage 42 to adjust the amount of gas flowing into the turbine 32. It should be noted that actually, each of a downstream portion of the intake passage 41 and an upstream portion of the exhaust passage 42 branches into branch passages, the number of which is equal to the number of cylinders 21, from a manifold. However, in FIG. 3 in order to simplify the drawing, each of the intake passage 41 and the exhaust passage 42 is shown as a single passage.

[0044] A radiator 43 is provided at the intake passage 41. The radiator 43 cools the air compressed by the compressor 31. A first pressure sensor 61 and a temperature sensor 65 are provided at the intake passage 41 so as to be located downstream of the radiator 43. The first pressure sensor 61 detects actual turbocharging pressure P that is discharge pressure of the compressor 31. The temperature sensor 65 detects a turbocharging temperature that is a temperature of the air introduced to the combustion chamber 20 through the intake passage 41. The first pressure sensor 61 may be provided at each above-described branch passage located downstream of the intake passage 41, or only one first pressure sensor 61 may be provided at the above-described manifold. Similarly, the temperature sensor 65 may be provided at each above-described branch passage located downstream of the intake passage 41, or only one temperature sensor 65 may be provided at the above-described manifold.

[0045] Moreover, a main fuel injection valve 51 (corresponding to a fuel injection mechanism of the present invention) is provided at the intake passage 41 for each cylinder 21. The main fuel injection valve 51 injects the fuel gas into the air discharged from the compressor 31. It should be noted that the fuel injection mechanism of the present invention does not necessarily have to be the fuel injection valve 51 as long as it injects the fuel gas into the air supplied to the gas engine 2. For example, the fuel injection mechanism may include: a fuel gas supply passage joined to an air supply passage connected to an inlet port of the compressor 31; and a fuel flow control valve provided at the fuel gas supply passage, and may inject the fuel gas into the air to be sucked into the compressor 31.

[0046] An intake valve 23 and an exhaust valve 24 are provided at each cylinder 21. The intake valve 23 opens or closes an intake port that is an opening formed at the intake passage 41 toward the combustion chamber 20. The exhaust valve 24 opens or closes an exhaust port that is an opening formed at the exhaust passage 42 toward the combustion chamber 20. An

ignition device 55 is provided at each cylinder 21. The ignition device 55 ignites an air-fuel mixture, constituted by the fuel gas and the air, in the combustion chamber.

[0047] In the present embodiment, the combustion chamber 20 is constituted by a main chamber 20A and a pre-chamber 20B. The main chamber 20A communicates with the intake passage 41 and the exhaust passage 42. The pre-chamber 20B is separated from the main chamber 20A by a dividing wall 25 at which communication holes are provided. The ignition device 55 is provided at the pre-chamber 20B. A sub fuel injection valve 52 injects the fuel gas into the pre-chamber 20B. The rich air-fuel mixture is formed in the pre-chamber 20B by the injection of the fuel gas from the sub fuel injection valve 52 and is ignited by the ignition device 55. With this, flame is generated in the pre-chamber 20B and is propagated into the main chamber 20A through the communication holes of the dividing wall 25. Thus, the lean air-fuel mixture in the main chamber 20A is also ignited. A second pressure sensor 62 is provided at the main chamber 20A. The second pressure sensor 62 detects cylinder internal pressure that is pressure in the main chamber 20A. The exhaust gas after the combustion is introduced from the combustion chamber 20 through the exhaust passage 42 to the turbine 32 and is used in the turbine 32 as force for driving the compressor 31.

[0048] **Configuration of Control System of Gas Engine System 1**

Hereinafter, the configuration of a control system of the gas engine system 1 will be described. FIG. 5 is a diagram showing the configuration of the control system for the gas engine system 1 and the marine propulsion device 8. The controller 7 includes a propulsion device control unit 71 and an engine control unit 72. The propulsion device control unit 71 controls operations of the marine propulsion device 8, and the engine control unit 72 controls operations of the gas engine system 1. The controller 7 is a so-called computer and includes a calculation processing portion (not shown), such as a CPU, and a storage portion (not shown), such as a ROM and a RAM. The storage portion stores programs executed by the calculation processing portion, various fixed data, and the like. The calculation processing portion transmits data to and receives data from external devices. Moreover, the calculation processing portion receives detection signals from various sensors and outputs control signals to various control targets. In the controller 7, the calculation processing portion reads and executes software, such as the programs stored in the storage portion. With this, the controller 7 performs processing of controlling the operations of the gas engine system 1 and the operations of the marine propulsion device 8. It should be noted that the controller 7 may execute processing by centralized control performed by a single computer or may execute processing by distributed control performed by a plurality of computers. Moreover, the controller 7 may be

constituted by a microcontroller, a programmable logic controller (PLC), or the like.

[0049] A rudder angle operating tool 73 and a ship steering operating tool 74 are provided at a pilothouse (not shown) provided at the hull. The rudder angle operating tool 73 is used to input the rudder angle, and the ship steering operating tool 74 is used to input the rotational frequency of the gas engine 2, forward movement, and backward movement. Rudder angle operation information input by a ship operator is input to the controller 7 through the rudder angle operating tool 73. Ship steering operation information input by the ship operator is input to the controller 7 through the ship steering operating tool 74. Each of these operating tools 73 and 74 may be, for example, a handle or a lever.

[0050] The controller 7 is communicably connected to the rudder angle operating tool 73, the ship steering operating tool 74, a ship speed meter 67, the turning driving device 84, and the turning angle sensor 66 through a wired or wireless information communication means.

[0051] The controller 7 controls the operation of the turning driving device 84 of the marine propulsion device 8 based on the rudder angle operation information input through the rudder angle operating tool 73, an actual turning angle detected by the turning angle sensor 66, and the like. Specifically, the controller 7 acquires the rudder angle operation information and the actual turning angle, calculates a target turning angle based on the rudder angle operation information, generates a turning angle instruction value such that the actual turning angle becomes the target turning angle, and outputs the turning angle instruction value to the turning driving device 84. In the turning driving device 84, the turning motor 96 operates based on the acquired turning angle instruction value. As a result, the actual turning angle of the propulsion blade 83 becomes the target turning angle corresponding to the rudder angle operation information.

[0052] Moreover, the controller 7 is communicably connected to the main fuel injection valve 51, the sub fuel injection valve 52, the ignition device 55, the first pressure sensor 61, the second pressure sensor 62, the phase angle detector 63, the temperature sensor 65, a jet assist valve 37, the intake blow off valve 48, and the exhaust wastegate valve 49 in the gas engine system 1 through a wired or wireless information communication means.

[0053] The controller 7 controls, for each cylinder 21, the fuel injection valves 51 and 52 and the ignition device 55 based on the phase angle detected by the phase angle detector 63. Specifically, the controller 7 performs a steady operation while a load changes little. When the load increases during the steady operation, the controller 7 switches to a load increase operation. In both the steady operation and the load increase operation, the controller 7 performs PID control of maintaining the actual rotational frequency N at a target rotational frequency N_T based

on an operation amount of the ship steering operating tool 74. It should be noted that the steady operation is an operation in which a fuel injection amount is substantially constant regardless of whether the load of the gas engine 2 is high or low. Examples of a factor that increases the load include: a ship speed-up command from the ship operator of the ship 11; a ship speed maintaining command input when the hull receives strong wind or waves; and an increase in propeller pitch when the propulsion blade 83 is a variable-pitch propeller.

[0054] In the present embodiment, the controller 7 calculates a required fuel injection amount Q corresponding to required output (i.e., an injection amount of the fuel gas required to obtain the required output). Specifically, the controller 7 calculates the required output of the gas engine 2 based on: the target rotational frequency N_T that is based on the operation amount of the ship steering operating tool 74; the actual rotational frequency N detected by the phase angle detector 63; an actual ship speed that is a current ship speed detected by the ship speed meter 67; a hull performance model prestored in the storage portion; and the like. Then, the controller 7 calculates a difference between the required output and an actual output and calculates the required fuel injection amount Q from the difference between the required output and the actual output. In the present embodiment, the fuel gas is intermittently injected from the main fuel injection valve 51. Therefore, the fuel injection amount denotes the amount of fuel gas injected once. It should be noted that if the fuel gas is continuously injected as with PTL 1, the fuel injection amount may denote the flow rate of the fuel gas.

[0055] **Method of Controlling Gas Engine System 1**

As described above, the controller 7 performs the steady operation while the load changes little, and performs the load increase operation when the load increases during the steady operation. Moreover, during the steady operation, the controller 7 performs load increase preparation processing of: predicting an increase in the load; and before the actual increase in the load, increasing a rotational frequency of the turbocharger while suppressing an increase in turbocharging pressure. The following will specifically describe (1) the steady operation, (2) the load increase operation, and (3) the load increase preparation processing in the gas engine 2. Control of one cylinder 21 in the gas engine 2 will be mainly described below, but the same control is performed for all the cylinders 21.

[0056] **(1) Steady Operation**

The gas engine 2 according to the present embodiment performs knocking control operation as the steady operation. It should be noted that the steady operation is not limited to the present embodiment as long as it is a control operation of adjusting the fuel injection amount and the turbocharging amount such that an excess air ratio falls within a range between a

knocking region and a misfire region.

[0057] The knocking control operation is an operation of optimizing an ignition timing to obtain highest efficiency in lean burn which is small in the amount of NOX discharged and can realize high efficiency. Specifically, in each cylinder 21 of the gas engine 2, the ignition timing is advanced or retarded for every predetermined number of cycles based on a difference between a knocking occurrence ratio and a target occurrence ratio during the predetermined number of cycles while maintaining an excess air ratio λ , which realizes the lean burn, constant.

Regarding the ignition timing, for example, a timing at which the piston 22 is located at the top dead center is set as a reference (0°), and how quickly the ignition is performed after the top dead center is shown by the phase angle of the gas engine 2.

[0058] In the knocking control operation, control is performed based on the cylinder internal pressure detected by the second pressure sensor 62. First, based on the cylinder internal pressure detected by the second pressure sensor 62, the controller 7 determines, for each cycle, whether a combustion state is a strong knocking state, a weak knocking state, a normal state, or a misfire state. Then, the controller 7 calculates a knocking occurrence ratio R ($R = \text{CyL}/\text{Cy}$) that is a ratio of a number CyL of cycles to a predetermined number Cy of cycles, the number CyL of cycles being the number of cycles in each of which the weak knocking state occurs.

[0059] After calculating the knocking occurrence ratio R , the controller 7 calculates a difference ΔR ($\Delta R = R_T - R$) between the knocking occurrence ratio R and a target occurrence ratio R_T . The target occurrence ratio R_T denotes a ratio by which high efficiency is obtained without significantly damaging the gas engine 2. The target occurrence ratio R_T is predetermined by an experiment or numerical simulation. As shown in FIG. 6, the target occurrence ratio R_T is set to a value slightly smaller than a knocking limit R_L . The controller 7 sets a value obtained by multiplying the calculated difference ΔR by a gain K , as a correction value β ($\beta = \Delta R \times K$) of the ignition timing. Then, the controller 7 sets a value obtained by adding the correction value β to a current ignition timing iT' , as a new ignition timing iT ($iT = iT' + \beta$). When the correction value β is a positive value, i.e., when the knocking occurrence ratio R is smaller than the target occurrence ratio R_T , the ignition timing is advanced by the correction value β . When the correction value β is a negative value, i.e., when the knocking occurrence ratio R is larger than the target occurrence ratio R_T , the ignition timing is retarded by the correction value β . Thus, the ignition timing iT is adjusted to an optimal timing.

[0060] **(2) Load Increase Operation**

When the load increases (i.e., the required fuel injection amount Q increases) during the steady operation, the controller 7 switches to the load increase operation. In the load increase operation, control is performed based on the actual turbocharging pressure P detected by the first pressure sensor 61, the turbocharging temperature detected by the temperature sensor 65, and the actual rotational frequency N of the gas engine 2 detected by the phase angle detector 63. FIG. 7 is a flow chart of the load increase operation.

[0061] First, the controller 7 calculates an increase rate V ($V = dQ/dt$) of the required fuel injection amount Q (Step S1). FIG. 8A shows that the degree of the increase in the load is relatively small, i.e., the increase rate V of the required fuel injection amount Q is low. FIG. 8B shows that the degree of the increase in the load is relatively large, i.e., the increase rate V of the required fuel injection amount Q is high.

[0062] Next, the controller 7 compares the calculated increase rate V with a threshold α (Step S2). As shown in FIG. 6, the fuel gas can be increased up to an excess air ratio first lower limit $\lambda 1$ that is a line passing through the knocking limit RL at the ignition timing iT adjusted in the knocking control operation.

[0063] When the fuel gas is increased, and the increase rate V of the required fuel injection amount Q is low, as shown in FIG. 8A, a timing B at which an actual fuel injection amount q becomes the required fuel injection amount Q is not delayed so much from an increase instruction termination point A of the required fuel injection amount Q . However, when the increase rate V of the required fuel injection amount Q is high, as shown by a two-dot chain line in FIG. 8B, the timing B at which the actual fuel injection amount q becomes the required fuel injection amount Q is largely delayed from the increase instruction termination point A of the required fuel injection amount Q . The threshold α is an increase rate when a delay from the increase instruction termination point A to the timing B is not allowable in a case where control is performed based on the first lower limit $\lambda 1$. Such threshold α is predetermined by an experiment or numerical simulation. It should be noted that the threshold α may be set for each actual fuel injection amount q and each actual rotational frequency N .

[0064] When the increase rate V of the required fuel injection amount Q is not more than the threshold α , the controller 7 proceeds to Step S3. When the increase rate V is larger than the threshold α , the controller 7 proceeds to Step S8. It should be noted that in the present embodiment, the controller 7 proceeds to Step S3 when the increase rate V is equal to the threshold α . However, the controller 7 may proceed to Step S8 when the increase rate V is equal to the threshold α .

[0065] In Step S3 and thereafter, while maintaining the ignition timing iT adjusted in the knocking control operation, the controller 7 gradually increases the actual fuel injection amount q such that the excess air ratio λ does not exceed the first lower limit $\lambda 1$. The excess air ratio λ can be calculated from the actual fuel injection amount q , the actual turbocharging pressure P detected by the first pressure sensor 61, and the turbocharging temperature detected by the temperature sensor 65.

[0066] First, the controller 7 selects an excess air ratio first lower limit $\lambda 1$ map shown in FIG. 9A (Step S3). In the excess air ratio first lower limit $\lambda 1$ map, excess air ratio first lower limits $\lambda 1_{i,k}$ ($1 \leq i \leq i$, $1 \leq k \leq j$) are determined in accordance with the actual fuel injection amounts q and the actual rotational frequencies N . The controller 7 determines the first lower limit $\lambda 1$ from the actual fuel injection amount q and the actual rotational frequency N by using the excess air ratio first lower limit $\lambda 1$ map (Step S4). It should be noted that the excess air ratio first lower limit $\lambda 1$ map may be a three-dimensional map which uses the turbocharging temperature as a variable in addition to the actual fuel injection amount q and the actual rotational frequency N .

[0067] After that, the controller 7 calculates a current excess air ratio λ from the actual fuel injection amount q , the actual turbocharging pressure P detected by the first pressure sensor 61, and the turbocharging temperature detected by the temperature sensor 65. Then, the controller 7 calculates a fuel injection amount increase amount Δq necessary to make the calculated excess air ratio λ become the first lower limit $\lambda 1$ determined in Step S4 (Step S5). The excess air ratio λ is a value obtained by dividing the amount of air actually supplied to the combustion chamber 20 and calculated from the actual turbocharging pressure P and the turbocharging temperature by a theoretical amount of air necessary to completely combust the fuel gas of the actual fuel injection amount q .

[0068] After the increase amount Δq is calculated, the controller 7 increases the actual fuel injection amount q by the increase amount Δq (Step S6) and determines whether or not the actual fuel injection amount q has become the required fuel injection amount Q or more (Step S7). When the actual fuel injection amount q is less than the required fuel injection amount Q , the controller 7 returns to Step S1. When the actual fuel injection amount q is the required fuel injection amount Q or more, the controller 7 terminates the load increase operation and returns to the steady operation.

[0069] On the other hand, in Step S8 and thereafter, the controller 7 retards the ignition timing iT by an angle ϵ and then gradually increases the actual fuel injection amount q such that

the excess air ratio λ does not exceed a second lower limit λ_2 smaller than the first lower limit λ_1 . As shown in FIG. 6, the second lower limit λ_2 is a line passing through the knocking limit RL when the ignition timing iT is retarded by the angle ε . With this, as shown in FIG. 8B, a timing C at which the actual fuel injection amount q becomes the required fuel injection amount Q is significantly advanced from the timing B.

[0070] First, the controller 7 retards the ignition timing iT by the angle ε (Step S8). The angle ε may be determined from the actual fuel injection amount q and the actual rotational frequency N or may be determined from the actual turbocharging pressure P detected by the first pressure sensor 61 and the actual rotational frequency N. Information indicating a relationship among the angle ε , the actual fuel injection amount q, and the actual rotational frequency N or information indicating a relationship among the angle ε , the actual turbocharging pressure P, and the actual rotational frequency N is prestored in the storage portion, and the controller 7 can calculate the angle ε by utilizing the information.

[0071] After the ignition timing iT is retarded, the controller 7 selects an excess air ratio second lower limit λ_2 map shown in FIG. 9B (Step S9). In the excess air ratio second lower limit λ_2 map, excess air ratio second lower limits $\lambda_{2i,k}$ ($1 \leq i \leq j$, $1 \leq k \leq j$) are determined in accordance with the actual fuel injection amounts q and the actual rotational frequencies N. Each second lower limit $\lambda_{2i,k}$ is smaller than the corresponding first lower limit $\lambda_{1i,k}$, i.e., the first lower limit $\lambda_{1i,k}$ determined in accordance with the actual fuel injection amount q and the actual rotational frequency N which are the same as the actual fuel injection amount q and the actual rotational frequency N in accordance with which the second lower limit $\lambda_{2i,k}$ is determined. The controller 7 determines the second lower limit λ_2 from the actual fuel injection amount q and the actual rotational frequency N by using the excess air ratio second lower limit λ_2 map (Step S10). It should be noted that the excess air ratio second lower limit λ_2 map may be a three-dimensional map which uses the turbocharging temperature as a variable in addition to the actual fuel injection amount q and the actual rotational frequency N.

[0072] After that, the controller 7 calculates the current excess air ratio λ from the actual fuel injection amount q, the actual turbocharging pressure P detected by the first pressure sensor 61, and the turbocharging temperature detected by the temperature sensor 65. Then, the controller 7 calculates the fuel injection amount increase amount Δq necessary to make the calculated excess air ratio λ become the second lower limit λ_2 determined in Step S10 (Step S11).

[0073] After the increase amount Δq is calculated, the controller 7 increases the actual fuel injection amount q by the increase amount Δq (Step S12) and determines whether or not the actual fuel injection amount q has become the required fuel injection amount Q or more (Step S13). When the actual fuel injection amount q is less than the required fuel injection amount Q , the controller 7 returns to Step S1. When the actual fuel injection amount q is the required fuel injection amount Q or more, the controller 7 terminates the load increase operation and returns to the steady operation.

[0074] **(3) Load Increase Preparation Processing**

In the turning thruster, a direction in which the propulsion blade 83 moves water can be changed by turning of the propulsion blade 83 (turning tube 82). However, the turning of the propulsion blade 83 may significantly increase the load of the gas engine 2 depending on a relationship with the ship speed, the ocean current, the wave direction, and the like.

[0075] FIG. 10 shows a graph of a time-lapse change of the actual turning angle of the propulsion blade 83 and a graph of a time-lapse change of the load of the gas engine 2. In FIG. 10, a time axis of the upper graph and a time axis of the lower graph correspond to each other. The lower graph of FIG. 10 shows the time-lapse change of the actual turning angle when the rudder angle operation information is input to the controller 7 at a time $T1$, and the turning angle changes from $\theta 1$ to $\theta 2$ based on a change in the rudder angle operation amount. The upper graph of FIG. 10 shows a change in the load of the gas engine 2 when the actual turning angle changes as above. The steady operation is being performed at the time $T1$ at which the rudder angle operation amount has changed. The load of the gas engine 2 starts increasing while the actual turning angle is changing from $\theta 1$ to $\theta 2$. To be specific, there is a time lag between the time $T1$ at which the rudder angle operation amount has changed and the actual start of the increase in the load of the gas engine 2 in response to the change in the rudder angle operation amount. In addition, there is a larger time lag between the time $T1$ at which the rudder angle operation amount has changed and the start of the load increase operation after the actual start of the increase in the load of the gas engine 2 in response to the change in the rudder angle operation amount.

[0076] At the time $T1$ at which the rudder angle operation amount has changed, the controller 7 can predict a future change in the load of the gas engine 2, the future change being caused by a change in the turning angle. To be specific, the controller 7 can predict the change in the load of the gas engine 2 before the load of the gas engine 2 changes by the change in the turning angle of the propulsion blade 83. Therefore, according to the gas engine system 1 of

the present embodiment, the change in the load by the change in the turning angle of the propulsion blade 83 is predicted based on the change in the rudder angle operation amount, and preparation is made by utilizing the above-described time lag such that the amount of air in the intake passage 41 (i.e., the amount of air which can be supplied to the combustion chamber 20) can be quickly increased before the load actually increases. With this, when the load actually increases, the turbocharging amount and the fuel gas can be quickly increased. Hereinafter, the load increase preparation processing performed by the controller 7 will be described with reference to the flow chart of FIG. 11.

[0077] During the steady operation, the controller 7 monitors the change in the rudder angle operation amount contained in the rudder angle operation information. The rudder angle operation amount is input by the operation of the above-described rudder angle operating tool 73 and may be input from an autopilot device (not shown) during an autopilot operation. As shown in FIG. 11, when the rudder angle operation amount changes during the steady operation (YES in Step S31), the controller 7 starts the load increase preparation processing (Step S32).

[0078] The controller 7 which has started the load increase preparation processing first calculates a predicted required fuel injection amount Q_p (Step S33). The predicted required fuel injection amount Q_p is one example of an index of the degree of the increase in the load. Specifically, the controller 7 acquires information, such as the target rotational frequency N_T based on the operation amount of the ship steering operating tool 74, the actual rotational frequency N that is the current rotational frequency of the gas engine 2, the target turning angle based on the operation amount of the rudder angle operating tool 73, the actual turning angle that is the current turning angle of the propulsion blade 83, and the actual ship speed that is the current ship speed. The controller 7 calculates predicted required output of the gas engine 2 from the above information by utilizing the hull performance model prestored in the storage portion. Then, the controller 7 calculates a difference between the predicted required output and the actual output and calculates the predicted required fuel injection amount Q_p from the difference between the predicted required output and the actual output.

[0079] The predicted required fuel injection amount Q_p may be a time-lapse change of the required fuel injection amount Q from when the propulsion blade 83 starts a turning operation in accordance with the rudder angle operation information until when the propulsion blade 83 terminates the turning operation. Or, the predicted required fuel injection amount Q_p may be a time-lapse change of the required fuel injection amount Q from when the propulsion blade 83 starts the turning operation in accordance with the rudder angle operation information until when a predetermined time elapses after the termination of the turning operation.

[0080] Next, the controller 7 calculates an increase rate V_p ($V_p = dQ_p/dt$) of the predicted required fuel injection amount Q_p (Step S34).

[0081] Then, the controller 7 compares the calculated increase rate V_p with a predetermined threshold α (Step S35). The threshold α may be the same value as the threshold α used in the above-described load increase operation. Or, the threshold α may be a value smaller or larger than the threshold α used in the load increase operation.

[0082] When the increase rate V_p of the predicted required fuel injection amount Q_p is not more than the threshold α (NO in Step S35), the controller 7 terminates the load increase preparation processing. In contrast, when the increase rate V_p of the predicted required fuel injection amount Q_p is larger than the threshold α (YES in Step S35), the controller 7 proceeds to Step S36 and then terminates the load increase preparation processing. In the present embodiment, when the increase rate V_p is equal to the threshold α , the controller 7 terminates the load increase preparation processing. However, when the increase rate V_p is equal to the threshold α , the controller 7 may proceed to Step S36.

[0083] In Step S36, the controller 7 performs a turbocharger rotational frequency increasing operation of increasing the rotational frequency of the turbocharger 3 while suppressing an increase in turbocharging pressure. By increasing the turbocharger rotational frequency as above before the load actually increases, the amount of air in the intake passage 41 (i.e., the amount of air which can be supplied to the combustion chamber 20) can be increased. Therefore, when the load actually increases, and the controller 7 switches from the steady operation to the load increase operation, the turbocharging pressure can be quickly increased such that the excess air ratio λ falls within an appropriate range. Thus, the actual fuel injection amount q can be increased more quickly. In other words, load responsiveness of the gas engine 2 (followability of the actual output with respect to the required output) can be improved.

[0084] The above turbocharger rotational frequency increasing operation may be one of the following steps (a) to (e) or a combination of two or more among the following steps (a) to (e).

[0085] **(a) Increase Excess Air Ratio λ**

Specifically, the controller 7 operates the intake blow off valve 48 such that the excess air ratio λ of the air-fuel mixture, constituted by the fuel gas and the air, to be supplied to the combustion chamber 20 is increased without exceeding the first lower limit λ_1 . With this, since the fuel is combusted in a state where the amount of air in the cylinder 21 is further larger, the combustion temperature increases, and the temperature of the exhaust gas from the gas engine 2 increases, i.e., exhaust energy increases. Therefore, the rotational frequency of the

turbine 32 of the turbocharger 3 can be increased.

[0086] **(b) Retard Ignition Timing**

Specifically, the controller 7 operates the ignition device 55 such that the ignition timing is retarded. With this, since the temperature of the exhaust gas from the gas engine 2 increases, i.e., the exhaust energy increases, the rotational frequency of the turbine 32 of the turbocharger 3 can be increased. Examples of an ignition system of the gas engine 2 include: a spark ignition system of igniting the air-fuel mixture by spark generated by a spark plug; and a pilot oil ignition system of igniting the air-fuel mixture by pilot fuel oil which has been injected into the combustion chamber 20 and self-ignited. The ignition device 55 of the spark ignition system includes a spark plug. The ignition device 55 operates so as to retard a generation timing of the spark of the spark plug. With this, the ignition timing can be retarded. Moreover, the ignition device 55 of the pilot oil ignition system includes a pilot fuel injection valve. The ignition device 55 operates so as to retard an injection timing of the pilot fuel from the pilot fuel injection valve. With this, the ignition timing can be retarded.

[0087] **(c) Perform Jet-assist of Rotation of Compressor 31 of Turbocharger 3**

In this case, a nozzle 36 and the jet assist valve 37 are provided (see FIG. 3). The nozzle 36 supplies high-pressure air, supplied from a high-pressure air source 35, to an inlet side of the compressor 31. The jet assist valve 37 is provided between the high-pressure air source 35 and the nozzle 36. Then, the controller 7 switches the jet assist valve 37 such that jet-assist of the rotation of the compressor 31 is performed by the high-pressure air jetting out from the nozzle 36. With this, the rotation of the compressor 31 is assisted by the flow of the high-pressure air, and as a result, the rotational frequency of the compressor 31 of the turbocharger 3 can be increased.

[0088] **(d) Reduce Gas Discharged from Exhaust Passage 42 to Outside of System**

Specifically, the controller 7 operates the exhaust wastegate valve 49 such that an opening degree of the exhaust wastegate valve 49 is made small, or the exhaust wastegate valve 49 is closed. When the opening degree of the exhaust wastegate valve 49 is made small, the amount of exhaust gas discharged from the exhaust passage 42 decreases. Therefore, the rotational frequency of the turbine 32 of the turbocharger 3 can be increased.

[0089] **(e) Reduce Opening Area of Nozzle of Turbine 32 when Turbocharger 3 is Variable Geometry Turbocharger**

When the turbocharger 3 is a variable geometry turbocharger in which an opening degree of a nozzle configured to spray exhaust gas to a turbine impeller is variable, the controller 7 operates the turbine 32 such that the opening area of the nozzle of the turbine 32 is made small.

By reducing the opening area of the nozzle of the turbine 32 as above, the flow velocity of the exhaust gas increases, and therefore, turbocharging efficiency can be increased.

[0090] In the turbocharger rotational frequency increasing operation, the controller 7 performs an operation of increasing the rotational frequency of the turbocharger 3 as above and an operation of suppressing an increase in the turbocharging pressure, the increase in the turbocharging pressure being caused due to the increase in the turbocharger rotational frequency. Specifically, the controller 7 increases the opening degree of the intake blow off valve 48 so as to suppress the increase in the turbocharging pressure, the increase in the turbocharging pressure being caused due to the increase in the turbocharger rotational frequency. When the opening degree of the intake blow off valve 48 increases, the amount of air discharged from the intake passage 41 increases. Therefore, even when the turbocharger rotational frequency increases, the increase in the turbocharging pressure can be suppressed. The controller 7 adjusts the opening degree of the intake blow off valve 48 such that, for example, a change in pressure detected by the first pressure sensor 61 falls within a predetermined width.

[0091] When the load increase preparation processing is switched to the load increase operation, the controller 7 reduces the opening degree of the intake blow off valve 48 or closes the intake blow off valve 48 based on the actual turbocharging pressure P and the turbocharging temperature so as to realize the actual turbocharging pressure P which satisfies the excess air ratio λ corresponding to the required fuel injection amount Q . Since the turbocharger rotational frequency of the turbocharger 3 has already been increased by the load increase preparation processing, the turbocharging pressure can be more quickly increased by reducing the opening degree of the intake blow off valve 48 or closing the intake blow off valve 48 than a case where the turbocharging pressure is increased after the load increase operation is started.

[0092] As described above, the gas engine control method according to the present embodiment is a method of controlling the gas engine 2 connected to the turbocharger 3 including the compressor 31 and the turbine 32, and the method includes: predicting the increase in the load of the gas engine 2 before the load of the gas engine 2 actually increases; when the degree of the predicted increase in the load exceeds the predetermined threshold α , increasing the turbocharger rotational frequency while suppressing the increase in the turbocharging pressure; and when the increase in the load of the gas engine 2 is detected, switching to the load increase operation and increasing the turbocharging pressure and the fuel injection amount. It should be noted that predicting the increase in the load, increasing the turbocharging pressure, and detecting the increase in the load of the gas engine 2 are performed during the steady operation.

[0093] Similarly, the gas engine system 1 according to the present embodiment includes: the turbocharger 3 including the compressor 31 and the turbine 32; the gas engine 2 connected to the compressor 31 through the intake passage 41 and also connected to the turbine 32 through the exhaust passage 42; the fuel injection mechanism (main fuel injection valve 51) configured to inject the fuel gas into the air to be supplied to the gas engine 2 through the intake passage; and the controller 7 configured to control the turbocharger 3, the gas engine 2, and the fuel injection mechanism. The controller 7 predicts the increase in the load of the gas engine 2 before the load of the gas engine 2 actually increases. When the degree of the predicted increase in the load exceeds the predetermined threshold α , the controller 7 performs processing of increasing the turbocharger rotational frequency while suppressing the increase in the turbocharging pressure. When the increase in the load of the gas engine is detected, the controller 7 (switches from the steady operation to the load increase operation and) performs processing of increasing the turbocharging pressure and the fuel injection amount.

[0094] According to the gas engine control method and the gas engine system 1, the increase in the load of the gas engine 2 is predicted before the load of the gas engine 2 actually increases. With this, preparation for increasing the turbocharging pressure can be made by increasing the turbocharger rotational frequency before the increase in the load. Therefore, when the load of the gas engine 2 actually increases, the turbocharging pressure and the fuel injection amount can be increased such that the excess air ratio falls within an appropriate range. With this, the load responsiveness of the gas engine 2 can be improved.

[0095] In the gas engine system 1 according to the present embodiment, the intake blow off valve 48 configured to discharge the gas from the intake passage 41 is provided at the intake passage 41. In the processing of increasing the turbocharger rotational frequency, the controller 7 increases the opening degree of the intake blow off valve 48 so as to suppress the increase in the turbocharging pressure, the increase in the turbocharging pressure being caused due to the increase in the turbocharger rotational frequency. In the processing of increasing the turbocharging pressure, the controller 7 controls the intake blow off valve 48 such that the opening degree of the intake blow off valve 48 is reduced, or the intake blow off valve 48 is closed.

[0096] With this, the turbocharger rotational frequency can be increased while suppressing the increase in the turbocharging pressure. Moreover, the turbocharging pressure can be quickly increased in a state where the turbocharger rotational frequency is increased while suppressing the increase in the turbocharging pressure (i.e., in a state where the load increase preparation processing is terminated).

[0097] Moreover, in the gas engine control method and the gas engine system 1 according to the above embodiment, the gas engine 2 is a main engine of the ship 11, and the predicted increase in the load of the gas engine 2 is an increase in the load of the gas engine 2 when the rudder angle changes in accordance with the change in the rudder angle operation amount of the ship 11.

[0098] More specifically, in the gas engine control method and the gas engine system 1 according to the above embodiment, the gas engine 2 is the main engine of the ship 11 including the turning thruster (marine propulsion device 8), and the predicted increase in the load of the gas engine 2 is an increase in the load of the gas engine 2 after the turning thruster starts turning in accordance with the change in the rudder angle operation amount of the ship 11.

[0099] Generally, in the ship 11, there is a time lag between when the rudder angle operation amount changes and when the load actually changes, but the load tends to change in short term. Even when the load steeply increases in such a situation, the turbocharger rotational frequency is being increased in advance, and therefore, the turbocharging pressure and the fuel injection amount can be quickly increased immediately after the increase in the load is detected by, for example, a decrease in the engine rotational frequency. On this account, adequate engine output can be immediately obtained in response to the steep increase in the load. In the present embodiment, the turning thruster is adopted as the marine propulsion device 8. However, a mechanism configured to determine a proceeding direction of the ship 11 may be a rudder plate driven by a hydraulic actuator or an electric actuator. Also in this case, a time lag may be generated between when the rudder angle operation amount changes and when the load actually increases after the rudder angle is changed by the operation of the hydraulic actuator or the electric actuator. By utilizing this time lag, the turbocharger rotational frequency can be increased in advance.

[0100] In the gas engine control method and the gas engine system 1 according to the embodiment, the turbocharger rotational frequency is increased by at least one of an operation of increasing the excess air ratio of the air-fuel mixture, constituted by the fuel gas and the air, to be supplied to the combustion chamber 20, an operation of retarding the ignition timing of the spark plug when the ignition device 55 is the spark ignition system, an operation of retarding the pilot fuel injection timing when the ignition device 55 is the pilot oil ignition system, an operation of performing the jet-assist of the rotation of the compressor 31, an operation of reducing the opening area of the nozzle of the turbine 32 when the turbocharger 3 is the variable geometry turbocharger, and an operation of reducing the gas discharged from the exhaust passage 42 of the combustion chamber 20 to an outside of the system.

[0101] For example, in order to increase the turbocharger rotational frequency, the controller 7 performs processing of reducing the opening degree of the intake blow off valve 48 so as to increase the excess air ratio of the air-fuel mixture, constituted by the fuel gas and the air, to be supplied to the combustion chamber 20. Moreover, for example, in order to increase the turbocharger rotational frequency, the controller 7 performs processing of operating the ignition device 55 so as to retard the ignition timing or the pilot fuel injection timing. Moreover, for example, in order to increase the turbocharger rotational frequency, the controller 7 performs processing of switching the jet assist valve 37 such that the jet-assist of the rotation of the compressor 31 is performed by the high-pressure air jetting out from the nozzle 36. Moreover, for example, in order to increase the turbocharger rotational frequency, the controller 7 performs processing of reducing the opening area of the turbine 32. Moreover, for example, in order to increase the turbocharger rotational frequency, the controller 7 performs processing of reducing the opening degree of the exhaust wastegate valve 49.

[0102] According to the above processing performed in order to increase the turbocharger rotational frequency, the turbocharger rotational frequency can be increased while suppressing influences on the steady operation of the gas engine 2.

[0103] The foregoing has explained a preferred embodiment of the present invention. The specific structures and/or functional details in the above embodiment may be modified within the scope of the present invention.

[0104] For example, in the load increase operation of the above embodiment, when the degree of the increase in the load is relatively large (when the increase rate V of the required fuel injection amount Q is larger than the threshold α), the ignition timing is retarded, and the fuel injection amount is gradually increased. However, when an adequate amount of air has already been prepared by the above-described load increase preparation processing at a timing at which the increase in the load is detected, only the operation of increasing the fuel injection amount may be performed.

[0105] Moreover, for example, in the above embodiment, the required fuel injection amount Q (predicted required fuel injection amount Q_p) is utilized as the index of the degree of the increase in the load of the gas engine 2. However, as the index of the load of the gas engine 2, at least one of a difference between the required output (predicted required torque) and the actual output, a difference between the target rotational frequency and the actual rotational frequency, and a difference between target turbocharging pressure and the actual turbocharging pressure may be used.

[0106] When the load increases, the actual rotational frequency of the gas engine 2

decreases from the target rotational frequency. The degree of the decrease in the actual rotational frequency depends on the degree of the load. Therefore, a difference between the target rotational frequency and the actual rotational frequency can be used as an index of the degree of the increase in the load.

[0107] Moreover, when the load increases, the target turbocharging pressure increases in accordance with the load, and an increase in the actual turbocharging pressure is delayed with respect to the increase in the target turbocharging pressure (so called turbo lag). Therefore, the difference between the actual turbocharging pressure and the target turbocharging pressure increases. In addition, the degree of the increase in the difference depends on the degree of the load. Therefore, the difference between the target turbocharging pressure and the actual turbocharging pressure can be used as the index of the degree of the increase in the load.

Industrial Applicability

[0108] The gas engine system of the present invention does not necessarily have to be used in ships and may be used in electric power generation facilities, construction machines, railcars, and the like.

Reference Signs List

- | | | |
|--------|----|--------------------------------|
| [0109] | 1 | gas engine system |
| | 2 | gas engine |
| | 3 | turbocharger |
| | 7 | controller |
| | 71 | propulsion device control unit |
| | 72 | engine control unit |
| | 8 | marine propulsion device |
| | 11 | ship |
| | 20 | combustion chamber |
| | 21 | cylinder |
| | 22 | piston |
| | 23 | intake valve |
| | 24 | exhaust valve |
| | 25 | dividing wall |
| | 31 | compressor |
| | 32 | turbine |

- 35 high-pressure air source
- 36 nozzle
- 37 jet assist valve
- 41 intake passage
- 42 exhaust passage
- 43 radiator
- 48 intake blow off valve
- 49 exhaust wastegate valve
- 51 main fuel injection valve
- 52 sub fuel injection valve
- 55 ignition device
- 61 first pressure sensor
- 62 second pressure sensor
- 63 phase angle detector
- 65 temperature sensor
- 66 turning angle sensor
- 67 ship speed meter
- 73, 74 operating tool
- 80 platform
- 81 upper gear box
- 82 turning tube
- 83 propulsion blade
- 84 turning driving device
- 85 clutch
- 86 input shaft
- 87 horizontal shaft
- 88, 89 upper bevel gear mechanism
- 90 vertical shaft
- 91, 92 lower bevel gear mechanism
- 93 propeller shaft
- 94 duct
- 95 turning gear
- 96 turning motor
- 97 driving gear

CLAIMS

1. A method of controlling a gas engine connected to a turbocharger including a compressor and a turbine,
the method comprising:
predicting an increase in a load of the gas engine before the load of the gas engine actually increases;
when a degree of the predicted increase in the load exceeds a predetermined threshold, increasing a rotational frequency of the turbocharger while suppressing an increase in turbocharging pressure; and
when the increase in the load of the gas engine is detected, increasing the turbocharging pressure and a fuel injection amount.
2. The method according to claim 1, wherein increasing the rotational frequency of the turbocharger includes at least one of:
increasing an excess air ratio of an air-fuel mixture to be supplied to a combustion chamber of the gas engine, the air-fuel mixture being constituted by fuel gas and air;
retarding an ignition timing;
retarding a pilot fuel injection timing;
performing jet-assist of rotation of the compressor;
reducing an opening area of a nozzle of the turbine; and
reducing gas discharged from an exhaust passage of the combustion chamber to an outside of the gas engine.
3. The method according to claim 1 or 2, wherein:
the gas engine is a main engine of a ship; and
the predicted increase in the load of the gas engine is an increase in the load of the gas engine when a rudder angle changes in accordance with a change in a rudder angle operation amount of the ship.
4. The method according to claim 1 or 2, wherein:
the gas engine is a main engine of a ship including a turning thruster; and
the predicted increase in the load of the gas engine is an increase in the load of the gas engine after the turning thruster has started turning in accordance with a change in a rudder angle operation amount of the ship.

5. A gas engine system comprising:
 - a turbocharger including a compressor and a turbine;
 - a gas engine connected to the compressor through an intake passage and also connected to the turbine through an exhaust passage;
 - a fuel injection mechanism configured to inject fuel gas into air to be supplied to the gas engine through the intake passage; and
 - a controller configured to control the turbocharger, the gas engine, and the fuel injection mechanism, wherein:
 - the controller predicts an increase in a load of the gas engine before the load of the gas engine actually increases;
 - when a degree of the predicted increase in the load exceeds a predetermined threshold, the controller performs processing of increasing a rotational frequency of the turbocharger while suppressing an increase in turbocharging pressure; and
 - when the increase in the load of the gas engine is detected, the controller performs processing of increasing the turbocharging pressure and a fuel injection amount.
6. The gas engine system according to claim 5, wherein:
 - the gas engine is mounted on a ship as a main engine; and
 - the predicted increase in the load of the gas engine is an increase in the load of the gas engine when a rudder angle changes in accordance with a change in a rudder angle operation amount of the ship.
7. The gas engine system according to claim 5, wherein:
 - the gas engine is a main engine of a ship including a turning thruster; and
 - the predicted increase in the load of the gas engine is an increase in the load of the gas engine after the turning thruster has started turning in accordance with a change in a rudder angle operation amount of the ship.
8. The gas engine system according to any one of claims 5 to 7, wherein:
 - an intake blow off valve configured to discharge gas from the intake passage is provided at the intake passage;
 - in the processing of increasing the rotational frequency of the turbocharger, the controller increases an opening degree of the intake blow off valve so as to suppress the increase

in the turbocharging pressure, the increase in the turbocharging pressure being caused due to the increase in the rotational frequency of the turbocharger; and

in the processing of increasing the turbocharging pressure, the controller controls the intake blow off valve such that the opening degree of the intake blow off valve is reduced, or the intake blow off valve is closed.

9. The gas engine system according to any one of claims 5 to 8, wherein:
an intake blow off valve configured to discharge gas from the intake passage is provided at the intake passage; and

the processing of increasing the rotational frequency of the turbocharger is processing of operating the intake blow off valve such that an excess air ratio of an air-fuel mixture to be supplied to a combustion chamber of the gas engine is increased, the air-fuel mixture being constituted by the fuel gas and the air.

10. The gas engine system according to any one of claims 5 to 8, wherein:
the gas engine includes an ignition device configured to ignite an air-fuel mixture constituted by the fuel gas and the air; and

the processing of increasing the rotational frequency of the turbocharger is processing of operating the ignition device such that an ignition timing or a pilot fuel injection timing is retarded.

11. The gas engine system according to any one of claims 5 to 8, wherein:
a nozzle and a jet assist valve are provided at the compressor, the nozzle being configured to supply high-pressure air, supplied from a high-pressure air source, to the compressor, the jet assist valve being provided between the high-pressure air source and the nozzle; and

the processing of increasing the rotational frequency of the turbocharger is processing of switching the jet assist valve such that jet-assist of rotation of the compressor is performed by the high-pressure air jetting out from the nozzle.

12. The gas engine system according to any one of claims 5 to 8, wherein:
the turbocharger includes a nozzle configured to spray exhaust gas to a turbine impeller, an opening degree of the nozzle being variable; and

the processing of increasing the rotational frequency of the turbocharger is

processing of reducing an opening area of the nozzle.

13. The gas engine system according to any one of claims 5 to 8, wherein:
an exhaust wastegate valve configured to discharge gas from the exhaust passage is provided at the exhaust passage; and
the processing of increasing the rotational frequency of the turbocharger is processing of reducing an opening degree of the exhaust wastegate valve.