(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 889 415 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
06.10.2021 Bulletin 2021/40

(51) Int Cl.:
F02F 3/14 *(2006.01)*

(21) Application number: 21159445.2

(22) Date of filing: 26.02.2021

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: 01.04.2020 JP 2020065717

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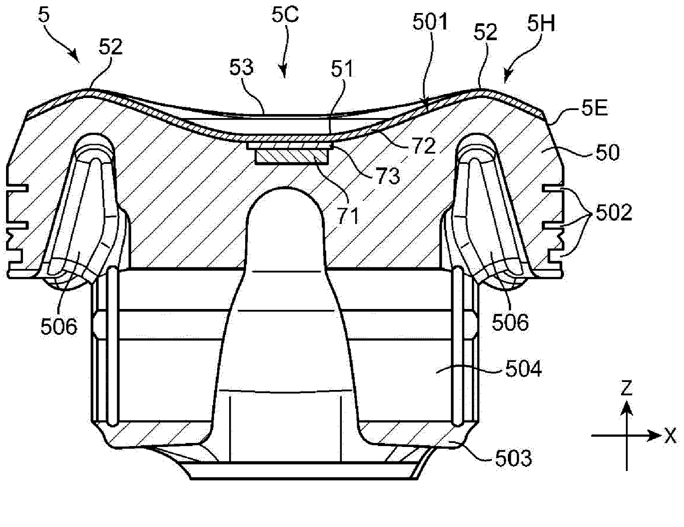
(54) PISTON, COMBUSTION-CHAMBER STRUCTURE ENGINE, AND VEHICLE

(57) A combustion chamber is partitioned by a cylinder block, a cylinder head, and a piston. The piston includes a piston body having an upper surface facing the combustion chamber, a heat-insulation layer provided at least in a central area, in a radial direction, of the upper surface and having smaller heat conductivity than the piston body, a heat-barrier layer provided to cover the upper surface and having smaller heat conductivity than the piston body and the heat-insulation layer, and a heat-diffusion layer provided between the heat-insulation layer and the heat-barrier layer and having larger heat conductivity than the heat-insulation layer and the heat-barrier layer. The heat-diffusion layer comprises a side end edge and an extension portion which contact with the piston body.

FIG. 3A



Printed by Jouve, 75001 PARIS (FR)

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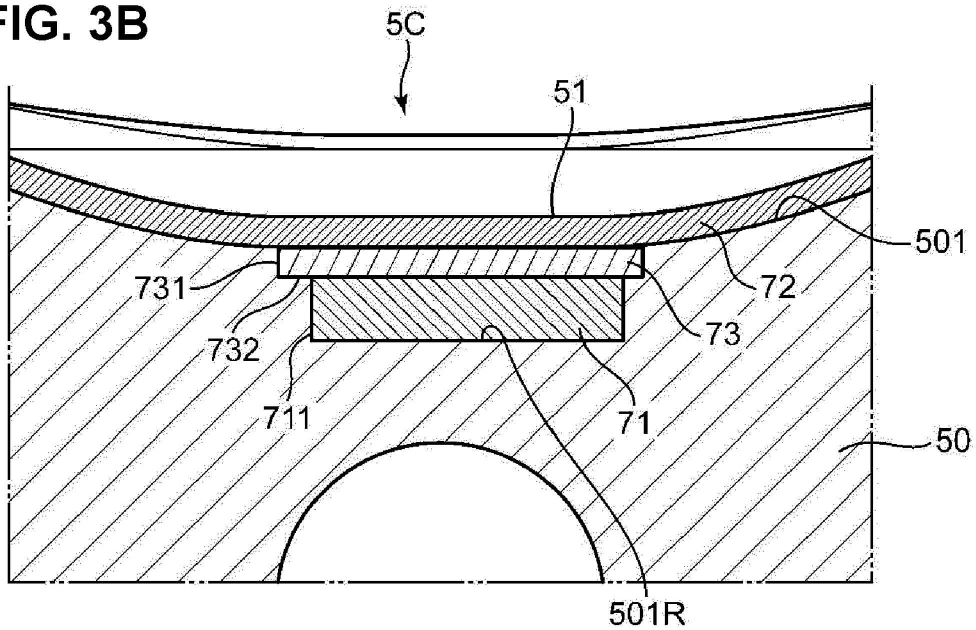
FIG. 3B



Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a piston, particularly a piston which comprises a heat-barrier layer to suppress heat loss. The present invention also relates to a combustion chamber, an engine, and a vehicle.

[0002] A combustion chamber of a gasoline engine or the like for a vehicle is required to decrease heat dissipation (heat loss) through a wall surface of the combustion chamber. A technology that a heat-barrier layer which is made of a small heat-conductivity material is coated on the combustion-chamber wall surface, such as a crown surface of a piston, for heat-loss reduction is known. A temperature difference between combustion gas generated in the combustion chamber and the combustion-chamber wall surface is made so small by providing the heat-barrier layer that the heat loss can be reduced.

[0003] A homogeneous-charge compression-ignition combustion engine (in other words, a premixed compression-ignition combustion engine) in which a mixture of premixed fuel and air is self-ignited in the combustion chamber is known as a kind of the gasoline engine. This homogeneous-charge compression-ignition combustion engine has features that the mixture combustion starts concurrently at every places in the combustion chamber. Thereby, there are merits of fuel-economy improvement, exhaust-gas purification, or the like. On the other hand, since flames which are generated instantly in the combustion chamber contact with the combustion-chamber wall surface, the heat loss through the combustion-chamber wall surface may improperly increase. Further, there is a problem that a pressure inside the combustion chamber, i.e., a cylinder internal pressure, may increase rapidly according to the above-described concurrent combustion of the mixture at every places in the combustion chamber. This increase of the cylinder internal pressure may cause a large combustion noise and apply a large load to the combustion chamber and various parts of an engine mechanism.

[0004] Japanese Patent Laid-Open Publication No. 2018-172997 discloses a combustion-chamber structure, as a countermeasure for this problem, in which a heat-barrier layer and a heat-insulation layer are provided at a piston crown surface. This heat-barrier layer covers an entire part of the piston crown surface, thereby suppressing the heat dissipation through a piston body. This heat-insulation layer is provided below the heat-barrier layer and in a central area, in a radial direction, of the piston crown surface, thereby making this central area be the area where the heat does not escape easily. Thereby, the self-ignition occurs at the central area, in the radial direction, of the combustion chamber and there occurs initial combustion at this central area. Subsequently, a flame (combustion) expands toward an outside area, in the radial direction, of the combustion chamber where the temperature is relatively low. Accordingly, the mixture can be burned slowly even if the homogeneous-charge compression-ignition combustion type is adopted, so that the heat loss and the rapid increase of the cylinder internal pressure can be suppressed.

[0005] The combustion-chamber structure disclosed in the above-described patent document is useful in the homogeneous-charge compression-ignition combustion at a relatively-low load engine operation, for example. However, it has been found that in the homogeneous-charge compression-ignition combustion or spark-ignition combustion at a relatively-high load engine operation, there occurs a problem that the above-described heat-insulation layer may store the heat excessively. That is, the heat-insulation layer may store the heat which has not been insulated (blocked) by the above-described heat-barrier layer, so that the heat-insulation layer having an increased temperature may heat the heat-barrier layer. Consequently, the cylinder internal temperature may increase and air taken in an intake stroke of the engine may be heated excessively, so that improper preignition may occur in a compression stroke of the engine.

SUMMARY OF THE INVENTION

[0006] An object of the present invention is to suppress the temperature increase of the heat-barrier layer which may cause the preignition, attaining the heat-loss reduction.

[0007] A first aspect of the present invention is a piston or a combustion-chamber structure for an engine including a cylinder block, a cylinder head, a piston, and a combustion chamber partitioned by the cylinder block, the cylinder head, and the piston. The piston includes a piston body which has an upper surface facing the combustion chamber, a heat-insulation layer which is provided at least in a central area, in a radial direction, of the upper surface of the piston body and has smaller heat conductivity than the piston body, a heat-barrier layer which is provided to cover the upper surface of the piston and has smaller heat conductivity than the piston body and the heat-insulation layer, and a heat-diffusion layer which is provided between the heat-insulation layer and the heat-barrier layer and has larger heat conductivity than the heat-insulation layer and the heat-barrier layer, and the heat-diffusion layer comprises a contact portion which contacts with the piston body.

[0008] According to the piston or the combustion-chamber structure of this first aspect of the present invention, the heat transferred to the heat-insulation layer is not stored at this heat-insulation layer and thereby a structure to make the heat escape toward the piston body can be provided. That is, the heat-diffusion layer is formed between the heat-insulation layer and the heat-barrier layer. This heat-diffusion layer has the larger heat conductivity than both the heat-insulation layer and the heat-barrier layer and comprises the contact portion contacting with the piston body. Accordingly, even if the heat-insulation layer has stored the heat, this stored heat can be made to transfer to the piston body through the heat-diffusion layer. That is, the heat stored at the heat-insulation layer can be made to escape to the piston body, without being made to transfer to the heat-barrier layer. Accordingly, the temperature increase of the heat-barrier layer is so suppressed that the increase of the cylinder internal temperature which may cause the preignition can be prevented properly.

[0009] In the above-described piston or combustion-chamber structure, it is preferable that the piston body comprise a cavity which is concaved downwardly, in a cylinder axial direction, at the upper surface, and the cavity be located at a position which corresponds to the central area, in the radial direction, of the upper surface of the piston.

[0010] The cavity forming area located at the central area, in the radial direction, of the combustion chamber increases its temperature during the combustion. According to this combustion-chamber structure, the heat-insulation layer is located at a portion of the position where the cavity is arranged. That is, the heat-insulation layer is provided at a back-face side of the heat-barrier layer in an area where the temperature of the piston becomes high during the combustion. Accordingly, a temperature difference between the combustion gas inside the combustion chamber and the heat-barrier layer (piston crown surface) can be made as small as possible, so that the heat loss can be reduced properly. Meanwhile, since the heat of the heat-insulation layer is made to escape to the piston body via the heat-diffusion layer, the temperature of the heat-barrier layer can be prevented from increasing excessively.

[0011] In the above-described piston or combustion-chamber structure, it is preferable that the heat-diffusion layer comprise an extension portion which extends outwardly, in the radial direction, from an outer peripheral edge of the heat-insulation layer, and the extension portion may be the contact portion which contacts with the piston body.

[0012] According to this piston or combustion-chamber structure, a contact area of the heat-diffusion layer with the piston body can be made properly large, compared to a case where the heat-diffusion layer and the heat-insulation layer have the same size and a side edge portion of the heat-diffusion layer is the contact portion contacting with the piston body. Accordingly, the heat of the heat-insulation layer can be made to easily escape to the piston body.

[0013] In the above-described piston or combustion-chamber structure, it is preferable that an outer peripheral edge of the heat-diffusion layer extend up to an outer peripheral edge of the upper surface of the piston body.

[0014] According to this piston or combustion-chamber structure, the heat of the heat-insulation layer can be made to more easily escape to the piston body.

[0015] In the above-described combustion-chamber structure, the combustion-chamber structure or an engine can further comprise an oil jet device to inject cooing oil, wherein the piston body comprises a penetration hole which penetrates the piston body in the cylinder axial direction, the heat-diffusion layer comprises a seal portion which seals a part of the penetration hole near the upper surface of the piston body, and the oil jet device is configured to inject the cooling oil from below the penetration hole toward the seal portion of the heat-diffusion layer.

[0016] According to this combustion-chamber structure or engine, the contact portion of the heat-diffusion layer with the piston body is so secured at the seal portion that a heat-dissipation path (route) of the heat-insulation layer can be secured. Additionally, the heat-diffusion layer can be cooled by the jet device's injecting the oil toward the seal portion. Accordingly, the temperature of the heat-barrier layer can be prevented from increasing excessively.

[0017] In the above-described piston or combustion-chamber structure, it is preferable that the heat conductivity of the heat-barrier layer be within a range of 0.05 - 1.50W/mK, and/or the heat conductivity of the heat-diffusion layer be within a range of 35 - 600W/mK.

[0018] Further, in the above-described combustion-chamber structure, it is preferable that the heat-barrier layer be made of heat-resistant silicon resin, and/or the heat-diffusion layer be made of copper-based material, Corson alloy, beryllium copper, fiber-reinforced aluminum alloy, or titanium aluminum.

[0019] Another aspect of the present invention is a combustion-chamber structure of an engine, comprising a cylinder block, a cylinder head, a piston, and a combustion chamber partitioned by the cylinder block, the cylinder head, and the piston, wherein the piston comprises a piston body which has an upper surface facing the combustion chamber, a heat-insulation layer which is provided only in a central area, in a radial direction, of the upper surface of the piston body and has smaller heat conductivity than the piston body, a heat-diffusion layer which is provided to cover an entire part of an upper surface of the heat-insulation layer and has larger heat conductivity than the heat-insulation layer, and a heat-barrier layer which is provided to cover at least both of an entire part of an upper surface of the heat-diffusion layer and an outside area, in the radial direction, of the upper surface of the piston body and has smaller heat conductivity than the piston body, the heat-insulation layer, and the heat-diffusion layer, and the heat-diffusion layer comprises a contact portion which contacts with the piston body.

[0020] Further another aspect of the present invention is a combustion-chamber structure of an engine, comprising a cylinder block, a cylinder head, a piston, and a combustion chamber partitioned by the cylinder block, the cylinder head, and the piston, wherein the piston comprises a piston body which has an upper surface facing the combustion chamber, a heat-insulation layer which is provided only in a central area, in a radial direction, of the upper surface of the piston body and has smaller heat conductivity than the piston body, a heat-diffusion layer which is provided to cover both of an entire part of an upper surface of the heat-insulation layer and an outside area, in the radial direction, of the upper surface of the piston body and has larger heat conductivity than the heat-insulation layer, and a heat-barrier layer which is provided to cover an entire part of an upper surface of the heat-diffusion layer and has smaller heat conductivity than the piston body, the heat-insulation layer, and the heat-diffusion layer, and the heat-diffusion layer comprises a contact portion which contacts with the piston body.

[0021] The combustion-chamber structures of the above-described other aspects of the present invention can provide substantially the same effects as that of the above-described aspect of the present invention.

[0022] The present invention will become apparent from the following description which refers to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023]

FIG. **1** is a schematic sectional view showing an engine to which a combustion-chamber structure according to an embodiment of the present invention is applied.

FIG. **2** is a plan view of a crown surface of a piston.

FIG. **3A** is a sectional view taken along line III-III of FIG. **2,** and FIG. **3B** is a major-part enlarged sectional view of FIG. **3A.**

FIG. **4** is a sectional view taken along line IV-IV of FIG. **2.**

FIG. **5** is a sectional view of a piston according to another embodiment.

FIG. **6** is a sectional view of a piston according to further another embodiment.

FIG. **7** is a chart showing materials which are applicable to respective structural members of the combustion-chamber structure of the engine.

FIG. **8** is a schematic diagram explaining a combustion manner of a homogeneous-charge compression-ignition combustion engine.

FIG. **9** is a schematic diagram explaining heat-insulation and heat-storage operations in a combustion-chamber structure of a comparative example.

FIG. **10** is a schematic diagram explaining a piston-surface temperature distribution in the combustion-chamber structure of the comparative example.

FIG. **11** is an explanatory diagram of preignition which may occur in the combustion-chamber structure of the comparative example.

FIGS. **12A** and **12B** are schematic diagrams explaining behaviors (operations) of heat in the combustion-chamber structure of the present embodiment.

FIG. **13** is a graph showing relationships between the depth from the piston surface (piston crown surface) and the wall temperature.

FIG. **14** is a schematic diagram explaining the piston-surface temperature distribution in the combustion-chamber structure of the present embodiment.

FIG. **15** is a schematic diagram explaining the piston-surface temperature distribution in the combustion-chamber structure of the present embodiment.

FIG. **16** is a schematic diagram explaining the piston-surface temperature distribution in the combustion-chamber structure of the present embodiment.

FIG. **17A** is a sectional view of the piston which shows an embodiment in a case where oil-jet cooling is applied, and FIG. **17B** is a sectional view showing a state where oil is injected to the piston.

FIG. **18** is a sectional view of the piston which shows another embodiment in the case where the oil-jet cooling is applied.

DETAILED DESCRIPTION OF THE INVENTION

[Entire Structure of Engine]

[0024] Hereafter, a piston or a combustion-chamber structure of an engine according to an embodiment of the present invention will be described specifically referring to the drawings. All of the features shown in the drawings may not necessarily be essential. FIG. **1** is a schematic sectional view showing an engine to which the combustion-chamber structure according to the embodiment of the present invention is applied. The engine described here is a multi-cylinder engine which includes cylinders and pistons and is installed to the vehicle as a power source for driving a vehicle, such as an automotive vehicle. The engine includes an engine body **1,** intake-exhaust manifolds, not illustrated, which are assembled to the engine body **1,** and auxiliary devices, such as various kinds of pumps.

[0025] The engine body **1** of the present embodiment is capable of performing the spark-ignition combustion (SI combustion) in which the mixture of fuel and air is ignited by spark in the combustion chamber and/or the homogeneous-charge compression-ignition combustion (HCCI combustion) in which the mixture is self-ignited. A principle ingredient of the fuel supplied to the engine body **1** is gasoline. Generally, the spark-ignition combustion is performed in a high-load high-speed engine operation, whereas the homogeneous-charge compression-ignition combustion is performed in a middle/low-load middle/low-speed engine operation at the engine body **1.** Operation ranges in which the SI combustion or the HCCI combustion are not limited. Herein, the present invention is applicable to a combustion chamber of the engine which is unable to perform the homogeneous-charge compression-ignition combustion.

[0026] The engine body **1** comprises a cylinder block **3,** a cylinder head **4,** and pistons **5.** The cylinder block **3** has plural cylinders **2** (only one of these is illustrated in the figure) which are arranged in a direction perpendicular to a paper plane of FIG. **1.** The cylinder head **4** is attached to an upper face of the cylinder block **3** so as to close respective upper openings of the cylinders **2.** The piston **5** is stored in each cylinder **2** such that the piston **5** reciprocates therein and connected to a crankshaft **7** via a connecting rod **8.** The crankshaft **7** rotates around a central axis thereof according to a reciprocating movement of the piston **5.**

[0027] A combustion chamber **6** is partitioned above the piston **5** (between the piston **5** and cylinder head **4**). An intake port **9** and an exhaust port **10** which respectively connect to the combustion chamber **6** are formed at the cylinder head **4.** At a bottom surface **4a** (ceiling surface **6U**) of the cylinder head **4** are formed an intake-side opening portion **41** which is a downstream end of the intake port **9** and an exhaust-side opening portion **42** which is an upstream end of the exhaust port **10.**

[0028] An intake valve **11** to open/close (open and/or close) the intake-side opening portion **41** and an exhaust valve **12** to open/close (open and/or close) the exhaust-side opening portion **42** are assembled to the cylinder head **4.** In a case of a double overhead camshaft (DOHC) type engine, for example, the two intake-side opening portions **41** and the two exhaust-side opening portions **42** are provided at each of the cylinders **2,** and the two intake valves **11** and the two exhaust valves **12** are provided as well. The number of the camshaft may be one. The intake valve **11** and the exhaust valve **12** are a poppet type of valve which comprises an umbrella part and a stem part, respectively.

[0029] In the present embodiment, the combustion chamber **6** is partitioned by the cylinder block **3,** the cylinder head **4,** and the piston **5.** More specifically, a combustion-chamber wall surface which partitions the combustion chamber **6** comprises an inner wall surface of the cylinder **2,** a piston crown surface **5H** (hereafter, referred to as a "crown surface **5H"** simply) which is the upper surface of the piston **5,** the combustion-chamber ceiling surface **6U** which is a bottom surface of the cylinder head **4,** and respective valve heads of the intake valve **11** and the exhaust valve **12.**

[0030] An intake-side valve driving mechanism **13** and an exhaust-side valve driving mechanism **14** which drive the intake valves **11** and the exhaust valve **12,** respectively, are provided at the cylinder head **4.** The respective stem parts of the intake valves **11** and the exhaust valve **12** are driven linked with the rotation of the crankshaft 7 by these valve driving mechanisms **13, 14.** Thus, the valve head of the intake valve **11** opens/closes the intake-side opening portion **41,** and the valve head of the exhaust valve **12** opens/closes the exhaust-side opening portion **42.**

[0031] The intake-side valve driving mechanism **13** comprises an intake-side variable valve timing mechanism (intake-side S-VT) **15.** The intake-side S-VT **15** is particularly an electrical type of S-VT which is provided at an intake camshaft and configured to change an opening/closing (opening and/or closing) timing of the intake valve **11** by continuously changing a rotational phase of the intake camshaft relative to the crankshaft **7** within a specified angle range. Likewise, the exhaust-side valve driving mechanism **14** comprises an exhaust-side variable valve timing mechanism (exhaust-side S-VT) **16.** The exhaust-side S-VT **16** is particularly an electrical type of S-VT which is provided at an exhaust camshaft and configured to change an opening/closing (opening and/or closing) timing of the exhaust valve **12** by continuously changing a rotational phase of the exhaust camshaft relative to the crankshaft **7** within a specified angle range.

[0032] A single spark plug **17** to supply ignition energy to the mixture in the combustion chamber **6** is attached to the cylinder head **4** for each cylinder **2.** The spark plug **17** is attached to the cylinder head **4** such that it is arranged at a central space, in a radial direction, of combustion chamber **6** and its ignition point is exposed to the inside of the combustion chamber **6.** The spark plug **17** discharges a spark from its tip according to a power supply from an ignition circuit, not illustrated, thereby igniting the mixture in the combustion chamber **6.** The ignition plug **17** of the present embodiment is used to perform the spark-ignition combustion in the high-load high-speed engine operation. The spark-ignition combustion and/or the homogeneous-charge compression-ignition combustion may be performed at any load and speed. Further, this is also used, when the homogeneous-charge compression-ignition combustion is performed, in a case where it is hard to perform the self-ignition right after an engine start in a cold time, the homogeneous-charge compression-ignition combustion is assisted under a specified load or speed conditions (spark assist), or the like.

[0033] A single injector **18** to inject the gasoline, as the principle ingredient of the fuel, from its tip portion into the combustion chamber **6** is attached to the cylinder head **4** for each cylinder **2.** A fuel supply pipe **19** is coupled to the injector **18.** The injector **18** injects the fuel supplied through the fuel supply pipe **19.** A high-pressure fuel pump (not illustrated) which includes a plunger type of pump and the like and is operationally connected to the crankshaft **7** is coupled to an upstream side of the fuel supply pipe **19.** A common rail for pressure accumulation which is common to the all cylinders **2** is provided between the high-pressure fuel pump and the fuel supply pipe **19.** The fuel pressure-accumulated in the common rail is supplied to the injector **18** of each cylinder **2,** and the high-pressure fuel is injected from the injector **18** into the combustion chamber **6.**

[Specific Structure of Piston]

[0034] Next, a structure of the piston **5** will be described specifically. FIG. **2** is a plan view of the piston **5.** FIG. **3A** is a sectional view taken along line III-III of FIG. **2,** and FIG. **3B** is a major-part enlarged sectional view of FIG. **3A.** FIG. **4** is a sectional view taken along line IV-IV of FIG. **2.** The piston **5** comprises a piston body **50,** a heat-insulation layer **71,** a heat-barrier layer **72,** and a heat-diffusion layer **73.** FIGS. **2 - 4** have directional indications of X, Y and Z. The X direction is an extension direction of the crankshaft 7, the Y direction is a direction in which the intake port **9** and the exhaust port **10** face each other (a sectional direction of FIG. **1**), and the Z direction is a cylinder axial direction (vertical direction).

[0035] The piston body **50** is a columnar body which has substantially the same size as a bore radius of the cylinder **2.** The piston body **50** comprises an upper surface **501** which faces the combustion chamber **6** and an outer peripheral edge **5E** which faces an inner wall of the cylinder **2.** One or plural ring grooves **502** where one or more piston rings are inserted are provided at the outer peripheral edge **5E.** A piston boss **503** and a skirt **505** are integrally provided at a lower side of the piston body **50.** A piston pin hole **504** for connecting the connecting rod **8** and the piston **5** is provided at the piston boss **503.** A cooling recess portion **506** which is opened downwardly is provided at a portion of the piston body **50** which is located near the outer peripheral edge **5E.** Cooling oil is injected to the cooling recess portion **506** from an oil jet nozzle, not illustrated.

[0036] The piston body **50** has a cavity **5C** which is concaved downwardly (i.e., toward the crankshaft 7), in the cylinder axial direction, at the upper surface **501.** The cavity **5C** is located at a position which corresponds to the central area, in the radial direction, of the upper surface **501.** The injector **18** which is positioned at a center, in the radial direction, of the combustion-chamber ceiling surface **6U** injects the fuel toward the cavity **5C.** As shown in FIG. **2,** the cavity **5C** is particularly of an oval shape which is long in the X direction, in a top view, and comprises a bottom face portion **51,** a pair of long-diameter side ridgeline portions **52,** and a pair of short-diameter side ridgeline portions **53.** The bottom face portion **51** is a nearly-flat circular area which is located at a deepest position of the cavity **5C.**

[0037] The long-diameter side ridgeline portion **52** is an opening edge, in the X direction, of the cavity **5C,** and projects highly the most at the upper surface **501.** In a direction toward an outward side, in the radial direction, of the upper surface **501,** an area extending from a peripheral edge of the bottom face portion **51** to the long-diameter side ridgeline portion **52** is an upward inclined surface, and an area extending from the long-diameter side ridgeline portion **52** to the outer peripheral edge **5E** is a downward inclined surface. The short-diameter side ridgeline portion **53** is an opening edge, in the Y direction, of the cavity **5C,** and projects up to a lower level than the long-diameter side ridgeline portion **52.** An area extending from the peripheral edge of the bottom face portion **51** to the short-diameter side ridgeline portion **53** is an upward inclined surface which goes up toward the outward side, in the radial direction, of the upper surface **501.** A downward inclined surface and a squish portion **54** are continuous on an outward side, in the radial direction, of the short-diameter side ridgeline portion **53.** The squish portion **54** is a half-moon shaped flat surface portion which is provided at an end portion, in the Y direction, of the upper surface **501.**

[0038] The combustion-chamber structure of the present embodiment is configured such that the crown surface **5H** of the piston **5** has a temperature gradient along the radial direction when the mixture in the combustion chamber **6** burns. The above-described temperature gradient is such that the temperature of a central area, in the radial direction, of the crown surface **5H** is relatively high, whereas the temperature of an outside area, in the radial direction, of the crown surface **5H** is relatively low. Meanwhile, the present combustion-chamber structure is configured such that heat dissipation (heat release) is possible through the piston body **50** so as to suppress the temperature from rising up to a high temperature which may cause preignition in the central area, in the radial direction, of the combustion chamber **6.** In order to provide such a combustion-chamber structure, the heat-insulation layer **71** is provided in the central area, in the radial direction, of the upper surface **501** of the piston body **50** according to the present embodiment. The heat-barrier layer **72** is preferably provided such that it perfectly or entirely covers the upper surface **501** where the heat-insulation layer **71** is provided. The heat-diffusion layer **73** is provided between the heat-insulation **71** and the heat-barrier layer **72.** Since this kind of laminate structure is formed at the upper surface **501,** the heat-barrier layer **72** is exposed to the piston crown surface **5H** which becomes an exposure face to the combustion chamber **6.**

[0039] The heat-insulation layer **71** is a circular member having a specified thickness in the Z direction in the top view. Of course, this circular shape is one example, and this layer **71** may has any other shape, such as a polygon. The heat-insulation layer **71** is provided at least in the central area, in the radial direction, of the upper surface **501.** FIGS. **3** and **4** show an example in which the heat-insulation layer **71** is located at a position which corresponds to the bottom face portion of the cavity **5C.** The heat-insulation layer **71** may be configured to extend up to the upward inclined surface positioned on the outward side, in the radial direction, of the bottom face portion **51,** the long-diameter side ridgeline portion **52** and/or the short-diameter side ridgeline portion **53,** or a further outward point, in the radial direction, from the long-diameter side ridgeline portion **52** and/or the short-diameter side ridgeline portion **53.** The thickness of the heat-insulation layer **71** can be selected from a range of 1 - 6mm or about 1 - about 6mm, for example.

[0040] It is preferable that the heat conductivity of the heat-insulation layer **71** be as small as possible from viewpoints of suppressing the heat from getting away (escaping) from the combustion chamber **6** through the piston **5** (suppressing the heat loss), and at least a material having the smaller heat conductivity than the piston body **50** be used. Further, it is preferable that the heat-insulation layer **71** have the volume specific heat which is as large as possible from, i.e., the superior heat-storage performance, from viewpoints of maintaining the central area, in the radial direction, of the crown surface **5H** at a properly high temperature.

[0041] The heat-barrier layer **72** covers the upper surface **501,** preferably an entire part of the upper surface **501** of the piston body **50** for the suppression of the heat loss through the crown surface **5H.** It is preferable that the heat-barrier layer **72** have the smaller heat conductivity than the piston body **50** and the heat-insulation layer from viewpoints of suppression of the heat dissipation from the crown surface **5H.** By providing the heat-barrier layer **72,** a temperature difference between the combustion gas generated in the combustion chamber **6** and the crown surface **5H** can be made properly small and thereby the heat loss can be reduced. Meanwhile, if the heat-barrier layer **72** has the large volume specific heat (heat storage performance) which is the same level as the heat-insulation layer **71,** the temperature of not only the central area, in the radial direction, of the crown surface **5H** but its outside area may be maintained at a high level, so that it may become difficult to make an effective temperature distribution. Therefore, it is preferable that the heat-barrier layer **72** have the smaller volume specific heat than the heat-insulation layer **71.** The thickness of the heat-barrier layer **72** can be selected from a range of 0.03 - 0.25mm, for example.

[0042] The heat-diffusion layer **73** is provided between the heat-insulation layer **71** and the heat-barrier layer **72** such that its lower surface contacts with the heat-insulation layer **71** and its upper surface contacts with the heat-barrier layer **72.** The heat-diffusion layer **73** is a layer which has the function of making the heat stored at the heat-insulation layer **71** escape to the piston body **50** so that the temperature of the crown surface **5H** does not increase too much at the arrangement of the heat-insulation layer **71.** It is preferable that the heat conductivity of the heat-diffusion layer **73** be as large as possible from viewpoints of immediately making the heat of the heat-insulation layer **71** transfer to the piston body **50.** Accordingly, the heat-diffusion layer **73** is configured to have the larger heat conductivity than the heat-insulation layer **71** and the heat-barrier layer **72.** The thickness of the heat-diffusion layer **73** can be selected from a range of 1 - 5mm or about 1 - about 5mm, for example. Herein, it is preferable from viewpoints of appropriate heat diffusion that the heat resistance which is represented by "heat conductivity/thickness" be as small as possible. Accordingly, the thickness, in the Z direction, of the heat-diffusion layer **73** is set considering the heat conductivity of a material used.

[0043] Referring to FIG. **3B,** the heat-diffusion layer **73** has a larger size than the heat-insulation layer **71.** That is, the heat-diffusion layer **73** has a side end edge **731** which is positioned on the outward side, in the radial direction, of an outer peripheral edge **711** of the heat-insulation layer **71.** Consequently, the heat-diffusion layer **73** comprises an extension portion **732** (contact portion) which extends outwardly, in the radial direction, beyond the outer peripheral edge **711** of the heat-insulation layer **71.** The end edge **731** and the extension portion **732** are portions which directly contact with the piston body **50.** The heat-diffusion layer **73** makes the heat which has not been insulated (blocked) by the heat-barrier layer **72** transfer to the heat-insulation layer **71.** Meanwhile, the heat-diffusion layer **73** receives the heat which has been excessively stored at the heat-insulation layer **71** and makes this heat transfer from the side end edge **731** and the extension portion **732** to the piston body **50.**

[0044] The heat-insulation layer **71** and the heat-diffusion layer **73** are stored in a recess portion **501R** which is formed at the upper surface **501** of the piston body **50.** That is, the heat-insulation layer **71** and the heat-diffusion layer **73** are positioned inside the recess portion **501R** such that these do not project from the bottom face portion **51** of the cavity **5C.** The heat-insulation layer **71** and the heat-diffusion layer **73** can be manufactured by a method that the recess portion **501R** is formed at the upper surface **501** previously and then sheets corresponding to the heat-insulation layer **71** and the heat-diffusion layer **73** are inserted with pressure into the recess portion **501R,** a method that these layers **71, 73** are welded to the bottom face portion **51** by a cast-in molding, or the like.

[0045] A casting of a metal-based material, such as aluminum alloy AC4B (the heat conductivity = 96W/mK or about 96W/mK, the volume specific heat = 2667kJ/m^{3}K or about 2667kJ/m^{3}K), can be used as a base material of the cylinder block **3** and the cylinder head **4.** Further, aluminum alloy AC8A (the heat conductivity = 125W/mK or about 125W/mK, the volume specific heat = 2600kJ/m^{3}K or about 2600kJ/m^{3}K) can be used as a base material of the piston **5** (piston body **50**).

[0046] A material which has the smallest heat conductivity and volume specific heat among the structural members of the piston **5** (the piston body **50,** the heat-insulation layer **71,** the heat-barrier layer **72,** and the heat-diffusion layer **73**) is selected for the heat-barrier layer **72** which is exposed to the crown surface **5H** of the piston **5.** That is, the structural material of the heat-barrier layer **72** is selected so that this layer **72** does not diffuse the heat very much and does not store the heat very much. A preferable range of the heat conductivity of the heat-barrier layer **72** is 0.05 - 1.50W/mK or about 0.05 - about 1.50W/mK, and a preferable range of the volume specific heat of the heat-barrier layer **72** is about 500 - 1500kJ/m^{3}K or about 500 - about 1500kJ/m^{3}K.

[0047] For example, heat-resistant silicon resin can be exemplified as the material of the heat-barrier layer **72** which meets the above-described requirements. The silicon resin made of three-dimensional polymer having the high branching degree which is represented by methyl silicon resin and methylphenyl silicon resin can be exemplified as the above-described silicon resin, and polyalkylphenylsiloxane or the like are preferably used, for example. This silicon resin may contain microballoon particles, such as Shirasu balloons. The heat-barrier layer

72 can be formed by a coating process in which the above-described silicon resin is coated on the upper surface **501** where the heat-insulation layer **71** and the heat-diffusion layer **73** are formed, for example.

[0048] The heat-insulation layer **71** is the layer which does not diffuse the heat very much but store the heat easily. A material which has the larger heat conductivity than the heat-barrier layer **72** but has the extremely-smaller heat conductivity than the piston body **50** is selected for the heat-insulation layer 71 for suppression of the heat diffusion. Further, a material which has the larger volume specific heat and heat resistance than the heat-barrier layer **72** is selected for the heat-insulation layer **71** for the appropriate heat storage performance. A preferable range of the heat conductivity of the heat-insulation layer **71** is 0.2 - 10W/mK or about 0.2 - about 10W/mK, and a preferable range of the volume specific heat of the heat-insulation layer **71** is about 800 - 3500kJ/m^{3}K.

[0049] A ceramics material can be exemplified as the material of the heat-insulation layer **71** which meets the above-described requirements, for example. In general, since the ceramics material has the small heat conductivity but has the larger volume specific heat and the superior heat resistance, this material is suitable for the heat-insulation layer **71.** Specifically, a preferable ceramics material is zirconia (the heat conductivity = 3W/mK or about 3W/mK, the volume specific heat = 2576kJ/m^{3}K or about 2576kJ/m^{3}K). Alternatively, the ceramics material, such as silicon nitride, silica, cordierite, or mullite, a porous SUS based material, calcium silicate, or the like can be used as the material of the heat-insulation layer **71** as well.

[0050] The heat-diffusion layer **73** makes the heat stored at the heat-insulation layer **71** escape to the piston body **50,** and therefore this layer **73** is the layer which easily diffuses the heat. Thus, the heat-diffusion layer **73** has the largest heat conductivity among the structural members of the piston **5.** A range of the preferable heat conductivity of the heat-diffusion layer **73** is about 35 - 600W/mK. Further, it is preferable that the thickness, in the Z direction, of the heat-diffusion layer **73** be set such that the heat resistance is within a range of 0.002 - 0.06m^{2}K/W or about 0.002 - 0.06m^{2}K/W. A copper-based material (the heat conductivity = 400W/mK or about 400W/mK, the volume specific heat = 3500kJ/m^{3}K or about 3500kJ/m^{3}K), Corson alloy, beryllium copper, fiber-reinforced aluminum alloy, titanium aluminum, or the like can be used as the material of the heat-diffusion layer **73** which meets the above-described requirements. The above-described copper-based material is particularly preferable because even in a case where the thickness is set at 2mm, the heat resistance of the heat-diffusion layer **73** can be suppressed at a value of 0.005m^{2}K/W or about 0.005m^{2}K/W.

[0051] While it is dispensable that the heat-diffusion layer **73** has the contact portion which contacts with the piston body **50,** its contract manner is selectable. FIG. **5** is a sectional view of a piston **5-1** according to another embodiment. The heat-insulation layer **71** and the heat-barrier layer **72** of the piston **5-1** shown in FIG. **5** are similar to those of the piston **5** disclosed in FIGS. **3** and **4.** However, a heat-diffusion layer **73A** of the piston **5-1** is set such that it has the same width size, in the radial direction, as the heat-diffusion layer **71.** That is, the outer peripheral edge **711** of the heat-insulation layer **71** and a side end edge **731A** of the heat-diffusion layer **73A** are located at the same position in the radial direction. This heat-diffusion layer **73A** has not have the extension portion **732** of the above-described heat-diffusion layer **73,** but the side end edge **731A** severs as the connection portion which connects with the piston body **50.** That is, the heat of the heat-insulation layer **71** gets away (escapes) to the piston body **50** through the side end edge **731A.** However, it is preferable that the extension portion **732** be provided because a contact area between the heat-diffusion layer **73** and the piston body **50** is so enlarged that the heat of the heat-insulation layer **71** can be made to escape to the piston body **50.**

[0052] FIG. **6** is a sectional view of a piston **5-2** according to further another embodiment. The heat-insulation layer **71** and the heat-barrier layer **72** of the piston **5-2** are similar to those of the piston **5** shown in FIGS. **3** and **4.** Meanwhile, a heat-diffusion layer **73B** of the piston **5-2** is set such that it has the same width size, in the radial direction, as the heat-barrier layer **72.** That is, a side end edge **731B** of the heat-diffusion layer **73B** extends up to the outer peripheral edge **5E** of the piston body **50.** Thereby, an upper surface of the heat-diffusion layer **73B** contacts with an entire part of a lower surface of the heat-barrier layer **72.** Further, a lower surface of the heat-diffusion layer **73B** contacts with an entire part of the upper surface **501** of the piston body **50** except an arrangement portion of the heat-insulation layer **71.** An contact are of the heat-diffusion layer **73B** with the piston body **50** can be made maximum, so that the heat of the heat-insulation layer **73B** can be distributed to the entire part of the upper surface **501** widely. Accordingly, the heat of the heat-insulation layer **71** can be made to escape to the piston body **50** further more.

[0053] FIG. **7** shows a preferred material selection example of the piston body **50,** the heat-insulation layer **71,** the heat-barrier layer **72,** and the heat-diffusion layer **73** of the piston **5.** FIG. 7 shows the heat conductivity λ, the volume specific heat pc, the heat diffusivity ($\lambda/\rho c$), the Z-directional thickness t, the heat resistance (t/λ), and the heat permeability ($\sqrt{\lambda\rho c}$) of each of these materials. Herein, a right-side small column of the heat diffusivity shows each value of the respective layers in a case where the heat diffusivity of the heat-barrier layer **72** is considered as "1".

[Significance of Heat-Insulation Layer]

[0054] Subsequently, the significance (performance) of the heat-insulation layer **71** and the heat-diffusion layer

73 which are described above will be described. Herein, this will be described by referring to the engine which is capable of performing the homogeneous-charge compression-ignition combustion. FIG. **8** is a schematic diagram explaining a combustion manner of the homogeneous-charge compression-ignition combustion engine. In FIG. **8,** a pent roof type of combustion chamber **60** is schematically shown and illustration of the cavity **5C** is omitted.

[0055] In the homogeneous-charge compression-ignition combustion engine, the mixture of the fuel and the air is self-ignited in the combustion chamber **60** by being compressed by the piston **5.** Accordingly, the combustion does not start from a compulsory ignition point like the spark-ignition combustion, but, as shown in FIG. **8,** plural ignition points **IP** occur at various places in the combustion chamber **60** and thereby the combustion (burning) of the mixture starts concurrently (at one time). This concurrent combustion causes a rapid increase of the pressure inside the combustion chamber **60** (cylinder internal pressure). Thereby, a large combustion noise is caused and a large load is applied to various engine-mechanism parts, such as a connecting portion between the connecting rod **8** and the crankshaft **7.** These may become hindering factors in practically applying the homogeneous-charge compression-ignition combustion engine. Moreover, since flames are generated instantly in the combustion chamber 6 according to this concurrent combustion, the heat dissipation (heat loss) through the above-described combustion-chamber wall surface, particularly the heat loss through the inner wall of the cylinder **2** which has a relatively low temperature, become improperly large. Accordingly, the heat efficiency of the engine may be deteriorated.

[0056] It may be considered that a uniform temperature distribution inside the combustion chamber **60** (combustion-chamber wall surface) causes the above-described scattering of the ignition points **IP** in the combustion chamber **60.** That is, since the temperature is uniform (homogeneous) inside the combustion chamber **60,** once the mixture is compressed in the engine compression stroke and this compression state reaches a specified condition, an ignition condition is established at every places in the combustion chamber **60.** In view of this matter, the present embodiment is configured such that the temperature gradient is actively formed in the radial direction of the combustion chamber **60,** i.e., at the crown surface **5H** of the piston **5.** Specifically, the temperature distribution is provided such that the temperature of the central area, in the radial direction, of the crown surface **5H** is relatively high, whereas the temperature of the outside area, in the radial direction, of the crown surface **5H** is relatively low.

[0057] FIG. **9** is a schematic diagram explaining heat-insulation and heat-storage operations in the combustion-chamber structure in which the piston **5** comprising the heat-barrier layer **72** and the heat-insulation layer **71** is used. The heat-barrier layer **72** has the extremely small heat conductivity as described above, so that its temperature changes according to the internal temperature of the combustion chamber **6.** Accordingly, the temperature difference between the combustion gas inside the combustion chamber **6** and the crown surface **5H** is made small, whereby the heat transfer to the piston body **50** can be suppressed to a certain degree. That is, as shown by an arrow **D1** in FIG. **9,** the heat can be prevented from escaping from the combustion chamber **6** through the crown surface **5H.** Thereby, the heat loss can be reduced. Herein, since the heat transfer cannot be insulated (blocked) perfectly by the heat-barrier layer **72,** the heat is made to transfer to a certain degree as shown by an arrow **D2** in FIG. **9.**

[0058] An area of the piston **5** where the heat-insulation layer **71** is provided has the small heat conductivity. That is, the heat-insulation layer **71** blocks the heat transfer from the combustion chamber **6** to the piston **5,** thereby suppressing the heat dissipation. Meanwhile, in another area where the heat-insulation layer **71** is not provided, the heat transfer from the combustion chamber **6** to the piston **5** is generated according to the heat conductivity of the piston **5.** While the above-described heat transfer is suppressed to a certain degree by providing the heat-barrier layer **72,** the larger heat transfer than the arrangement area of the heat-insulation layer **71** is generated. Further, the heat-insulation layer **71** of the present embodiment is made of the material having the larger volume specific heat, thereby performing the superior heat storage. Accordingly, the heat passed through the heat-barrier layer **72** (the arrow **D2**) and the heat around there (the arrow **D3**) are stored at the heat-insulation layer **71.**

[0059] Then, the heat-insulation layer **71** where the heat has been stored comes to heat the above-positioned heat-barrier layer **72.** Accordingly, the temperature of the central area, in the radial direction, of the crown surface **5H** where the heat-insulation layer **71** is provided can be maintained at the higher one, compared to the temperature of its outside area. This temperature gradient is formed in the radial direction, so that the homogenous-charge compression-ignition combustion in the combustion chamber **6** can be configured such that the combustion (burning) of the mixture changes (moves) from an inside space to an outside space, in the radial direction, of the combustion chamber **6.** That is, the concurrent ignition-and-combustion at the plural places in the combustion chamber **60,** which is shown in FIG. **8,** does not happen, but there occurs a slow combustion where the mixture burns gradually from the central area, in the radial direction, of the combustion chamber **6** to the outside area, in the radial direction, of the combustion chamber **6.** Accordingly, in the homogeneous-charge compression-ignition combustion, the combustion noise and the mechanical load can be reduced and the heat loss can be improved.

[Significance of Heat-Diffusion Layer]

[0060] It can be prevented by providing the heat-diffusion layer **73** between the heat-insulation layer **71** and the heat-barrier layer **72** that the temperature of the arrangement area of the heat-insulation layer **71** on the crown surface **5H** increases excessively. FIG. **10** is a schematic diagram explaining the temperature distribution of the crown surface **5H** (piston-surface temperature distribution) according to a comparative example. A combustion-chamber of the comparative example is substantially the same as that of the above-described embodiment in a structure in which the heat-insulation layer **71** is provided in the central area, in the radial direction, of the crown surface **5H** and the entire part of the crown surface **5H** is covered with the heat-barrier layer **72,** but different from that of the above-described embodiment in a structure in which the heat-diffusion layer **73** does not exist.

[0061] A temperature distribution **L1** of FIG. **10** shows a piston-surface temperature in the low-load engine operation. As described above, the engine body **1** of the present embodiment performs the homogeneous-charge compression-ignition combustion in which a lean mixture is used in the low-load engine operation. Since the amount of fuel injection from the injector **18** is relatively small in the low-load engine operation, the temperature of the combustion gas in the combustion chamber **6** is relatively low. Accordingly, the temperature of the piston surface is low as a whole as well. Herein, since the heat-insulation layer **71** is provided in the central area, in the radial direction, of the crown surface **5H,** the piston-surface temperature of the above-described central area becomes high as described above. Accordingly, the temperature distribution **L1** is configured such that the central area, in the radial direction, which corresponds to the arrangement area of the heat-insulation layer **71** has the high temperature and the outside area, in the radial direction, which corresponds to the non-arrangement area of the heat-insulation layer **71** has the low temperature.

[0062] A temperature distribution **L2** of FIG. **10** shows the piston-surface temperature in the middle/high-load engine operation. The engine body **1** performs the homogenous-charge compression-ignition combustion using the lean mixture in the middle-load engine operation, and performs the spark-ignition combustion with an air-fuel ratio: $\lambda = 1$ in the high-load engine operation. A distribution tendency of the temperature distribution **L2** is the same as the temperature distribution **L1,** in which the temperature in the central area, in the radial direction, of the piston surface is high and the temperature in the outside area, in the radial direction, of the piston surface is low. However, since the amount of fuel injection becomes relatively large in the middle/high-load engine operation, the temperature of the combustion gas inside the combustion chamber **6** becomes relatively high. Accordingly, the piston surface temperature becomes high as a whole as well, and the heat-insulation layer **71** comes to store the high-temperature heat as well. Thus, the heat-barrier layer **72** is heated by this heat-insulation layer **71,** so that the temperature distribution **L2** shows the distribution in which the central area, in the radial direction, of the piston surface where the heat-insulation layer **71** is provided has a particularly high temperature.

[0063] FIG. **11** is an explanatory diagram showing a phenomenon which may occur in the middle/high-load engine operation in the combustion-chamber structure of the comparative example. In a case where the central area, in the radial direction, of the crown surface **5H** (heat-barrier layer **72**) comes to have the extremely high temperature like the temperature distribution **L2** of FIG. **10,** the cylinder internal temperature is made excessively high. Thereby, when the temperature of the air taken in into the combustion chamber **6** in the engine intake stroke becomes higher and then this heated air is compressed in the engine compression stroke, preignitions **PIG** may occur. That is, there may occur the phenomenon in which part of the mixture has been ignited at an earlier timing than a normal compression-ignition timing. In this case, an improper torque fluctuation or output decrease may be caused.

[0064] FIGS. **12A** and **12B** are schematic diagrams explaining behaviors (operations) of the heat in the combustion-chamber structure of the present embodiment. FIG. **12A** shows the behavior of the heat in the low-load engine operation. Similarly to the comparative example, the heat-barrier layer **72** prevents the heat from escaping from the combustion chamber **6** through the crown surface **5H** (arrow **D1**). Herein, since the heat-barrier layer **72** cannot block the heat transfer perfectly, the heat may pass through to a certain degree (arrow **D2**). This heat having passed through comes into the heat-diffusion layer **73,** and since the heat-diffusion layer **73** has the high heat conductivity, the heat is made to transfer to the heat-insulation layer **71.** Further, the heat-diffusion layer **73** makes the heat of the piston body **50** transfer to the heat-insulation layer **71** (arrow **D4**). The heat of the piston body **50** transfers to the heat-insulation layer **71** directly as well (arrow **D3**). The heat-insulation layer **71** stores this heat, and consequently, the temperature distribution in which the temperature of the central area, in the radial direction, of the crown surface **5H** which corresponds to the arrangement area of the heat-insulation layer **71** is high, whereas the temperature of the outside area, in the radial direction, of the crown surface **5H** which corresponds to the non-arrangement area of the heat-insulation layer **71** is low is formed.

[0065] FIG. **12B** shows the behavior of the heat in the middle/high-load engine operation. In the middle/high-load engine operation, the combustion-gas temperature in the combustion chamber **6** becomes high and the heat-barrier layer **72** blocks (arrow **D1**), but the heat having higher temperature and larger heat capacity passes through the heat-barrier layer **72** (arrow **D2**). At the arrangement position of the heat-insulation layer **71,** the heat having passed through the heat-barrier layer **72**

comes into the heat-diffusion layer **73** and transfers to the heat-insulation layer **71.** Accordingly, the temperature of the heat-insulation layer **71** becomes high. However, when the temperature of the heat-insulation layer **71** becomes higher than that of the piston body **50,** the heat-diffusion layer **73** makes the heat of the heat-insulation layer **71** transfer to the piston body **50** (arrow **D5**). That is, the heat-diffusion layer **73** performs the function of heat dissipation of the heat of the heat-insulation layer **71** to the piston body **50.** Thereby, the temperature of the central area, in the radial direction, of the crown surface **5H** which corresponds to the arrangement area of the heat-insulation layer **71** can be prevented from becoming excessively high.

[0066] FIG. **13** is a graph showing relationships between the depth from the piston surface (crown surface **5H**) and the wall temperature. The wall temperature at a point which is 0mm depth from the piston surface is the wall temperature of the crown surface **5H,** and respective wall temperatures of the central areas, in the radial direction, of temperature characteristics **H1** - **H10** based on the various kinds of combustion-chamber structure are plotted. The graph of FIG. **13** shows that in the low-load engine operation, even if the heat-diffusion layer **73** is provided between the heat-insulation layer **71** and the heat-barrier layer **72,** the temperature of the central area, in the radial direction, of the crown surface **5H** can be made high similarly to a case where the heat-diffusion layer **73** is not provided (FIG. **10**). Herein, measuring conditions are that a compression ratio of the engine body **1** is 17, an engine speed is 2000rpm, and the engine load is 1/4.

[0067] The temperature characteristic **H1** (106°C) of FIG. **13** is the characteristic of a piston which is not provided with the heat-insulation layer **71,** the heat-barrier layer **72,** and the heat-diffusion layer **73** (an upper surface **501** of the piston body **50** is exposed). The temperature characteristic **H2** (243°C) of FIG. **13** is the characteristic of a piston which is provided with the heat-barrier layer **72** having a thickness of 75μm on the upper surface **501** only. The wall temperature of these temperature characteristics **H1, H2** is low, so that it is apparent that the temperature distribution in which the temperature of the central area, in the radial direction, of the crown surface **5H** does not become high in the low-load engine operation can be provided.

[0068] The temperature characteristics **H3, H4** are the characteristics of a case where the heat-insulation layer **71** is provided on the upper surface **501** only. The temperature characteristic **H3** shows a case where the thickness of the heat-insulation layer **71** is 2mm, and the temperature characteristic **H4** shows a case where the thickness of the heat-insulation layer **71** is 3mm. The temperature characteristics **H5, H6** are the characteristics of a case where the heat-insulation layer **71** and the heat-barrier layer **72** are provided on the upper surface **501** (a structure of the comparative example shown in FIG. **9**). The temperature characteristic **H5** shows a case where the thickness of the heat-barrier layer **72** is 75μm and the thickness of the heat-insulation layer **71** is 2mm, and the temperature characteristic **H6** shows a case where the thickness of the heat-barrier layer **72** is 75μm and the thickness of the heat-insulation layer **71** is 3mm. The wall temperature of the temperature characteristics **H3, H5** is 424°C and the wall temperature of the temperature characteristics **H4, H6** is 452°C, so that it is apparent that the temperature distribution in which the temperature of the central area, in the radial direction, of the crown surface **5H** becomes sufficiently high in the low-load engine operation can be provided.

[0069] The temperature characteristics **H7 - H10** are the characteristics of the piston according to the present embodiment where the heat-insulation layer **71,** the heat-barrier layer **72,** and the heat-diffusion layer **73** are provided on the upper surface **501.** The temperature characteristic **H7** shows a case where the thickness of the heat-barrier layer **72** is 75μm, the thickness of the heat-insulation layer **71** is 2mm, and the heat-diffusion layer **73** is made of the aluminum alloy having the thickness of 2mm. The temperature characteristic **H8** is substantially the same as the temperature characteristic **H8** except the heat-insulation layer **71** having the thickness of 3mm. The temperature characteristic **H9** shows a case where the thickness of the heat-barrier layer **72** is 75μm, the thickness of the heat-insulation layer **71** is 2mm, and the heat-diffusion layer **73** is made of the SUS based material having the thickness of 2mm. The temperature characteristic **H10** is substantially the same as the temperature characteristic **H9** except the heat-insulation layer **71** having the thickness of 3mm.

[0070] The wall temperature of the temperature characteristics **H7, H9** (the thickness of the heat-insulation layer **71** is 2mm) is 427°C and the wall temperature of the temperature characteristics **H8, H10** (the thickness of the heat-insulation layer **71** is 2mm) is 455°C. The wall temperature of the temperature characteristics **H7, H9** is nearly equal to the wall temperature of the temperature characteristics **H3, H5** (424°C) of the case where the thickness of the heat-insulation layer **71** is 2mm. Further, the wall temperature of the temperature characteristics **H8, H10** is nearly equal to the wall temperature of the temperature characteristics **H4, H6** (452°C) of the case where the thickness of the heat-insulation layer **71** is 3mm. Accordingly, even in the case where the heat-diffusion layer **73** is provided between the heat-insulation layer **71** and the heat-barrier layer **72,** the temperature distribution in which the temperature of the central area, in the radial direction, of the crown surface **5H** is sufficiently high in the low-load engine operation can be provided.

[0071] FIGS. **14** - **16** are schematic diagrams for explaining the piston-surface temperature distributions in the combustion-chamber structures of the present embodiment. The combustion-chamber structures shown in FIGS. **14 - 16** show examples in which these structures have a common structure in which the heat-insulation layer **71** is provided at the central area, in the radial direction, of the crown surface **5H** and the entire part of the crown surface **5H** is covered with the heat-barrier layer **72,** whereas these structures are different from each other in a radial-direction width of the heat-diffusion layer **73.**

[0072] FIG. **14** is the combustion-chamber structure which corresponds to the piston **5-1** shown in FIG. **5,** and the radial-direction width of the heat-diffusion layer **73A** has the same size as the heat-insulation layer **71.** In this embodiment, as described above, the heat of the heat-insulation layer **71** is made to escape from the side end edge **731A** of the heat-diffusion layer **73** to the piston body **50.** A temperature distribution **L11** shown in FIG. **14** shows a surface temperature (the temperature of the crown surface **5H**) of the piston **5-1** in the low-load engine operation. This temperature distribution is equivalent to the temperature distribution **L1** which is shown in FIG. **10** as the comparative example. The temperature distribution **L11** is configured such that the temperature of the central area, in the radial direction, of the crown surface **5H** which corresponds to the arrangement area of the heat-insulation layer **71** is high and the temperature of the outside area, in the radial direction, of the crown surface **5H** which corresponds to the non-arrangement area of the heat-insulation layer **71** is low. Accordingly, the slow combustion where the mixture burns gradually from the central area, in the radial direction, of the combustion chamber **6** to the outside area, in the radial direction, of the combustion chamber **6** can be made to occur in the low-load engine operation.

[0073] The temperature distribution **L21** of FIG. **14** shows the surface temperature of the piston **5-1** in the middle/high-load engine operation. The temperature distribution **L2** of the comparative example in the middle/high-load engine operation which is shown by a dotted line is added for comparison. Since the temperature of the combustion gas inside the combustion chamber **6** becomes relatively high in the middle/high-load engine operation, the piston surface temperature of the temperature distribution **L21** becomes relatively high as a whole compared to the temperature distribution **L11** of the low-load engine operation.

[0074] However, the piston surface temperature of the central area, in the radial direction, in the temperature distribution **L21** is considerably lowered compared to the temperature distribution **L2** of the comparative example. This is because the heat-diffusion layer **73** makes the heat stored at the heat-insulation layer **71** escape to the piston body **50.** A heating degree of the heat-insulation layer **72** positioned right above the heat-insulation layer **71** is decreased by the above-described heat-escaping (heat dissipation) caused by the heat-diffusion layer **73,** so that the piston surface temperature lowers. Herein, the piston surface temperature of the outside area, in the radial direction, in the temperature distribution **L21** increases slightly, compared to that in the temperature distribution **L2** of the comparative example, because of the above-described heat dissipation to the piston body **50.** However, it can be considered that the surface temperature of the entire part of the crown surface **5H** in the temperature distribution **L21** decreases more than that in the temperature distribution **L2** of the comparative example. Accordingly, the intake air is not heated so excessively that the above-described preignition can be suppressed from occurring.

[0075] FIG. **15** shows the combustion chamber which corresponds to the piston **5** shown in FIGS. **3** and **4,** in which the heat-diffusion layer **73** has a slightly larger size than the heat-insulation layer **71.** In this embodiment, as described above, the heat of the heat-insulation layer **71** is made to escape from the side end edge **731** and the extension portion **732** of the heat-diffusion layer **73** to the piston body **50.** The temperature distribution **L12** shown in FIG. **15** shows the surface temperature of the piston **5** in the low-load engine operation. This temperature distribution **L12** is equivalent to the temperature distribution **L11** shown in FIG. **14,** in which the temperature of the central area, in the radial direction, is high and the temperature of the outside area, in the radial direction, is low.

[0076] The temperature distribution **L22** shown in FIG. **15** shows the surface temperature of the piston **5** in the middle/high-load engine operation. Herein, the temperature distribution **L2** of the comparative example which is shown by a dotted line is added as well. The piston surface temperature of the central area, in the radial direction, in the temperature distribution **L22** is considerably lowered compared to the temperature distribution **L2** of the comparative example. Further, this piston surface temperature is also lowered compared to the temperature distribution **L21** shown in **FIG. 14.** This is because the heat-diffusion layer **73** is provided with not only the side end edge **731** but the extension portion **732** as the contact surface with the piston body **50,** so that the much more heat which has been stored at the heat-insulation layer **71** is made to escape to the piston body **50.**

[0077] FIG. **16** shows the combustion-chamber structure which corresponds to the piston **5-2** shown in FIG. **6,** in which the radial-direction width of the heat-diffusion layer **73B** is the same as that of the heat-barrier layer **72.** In this embodiment, since the heat-diffusion layer **73B** contacts with the piston body **50** except the arrangement portion of the heat-insulation layer **71,** the heat of the heat-insulation layer **71** is made to escape to the entire area of the piston body **50.** The temperature distribution **L13** shown in FIG. **16** shows the surface temperature of the piston **5-2** in the low-load engine operation. This temperature distribution **L13** is equivalent to the temperature distributions **L11, L12** shown in FIGS. **14** and **15,** in which the temperature of the central area, in the radial direction, is high and the temperature of the outside area, in the radial direction, is low.

[0078] The temperature distribution **L23** shown in FIG. **16** shows the surface temperature of the piston **5-2** in the middle/high-load engine operation. Herein, the temperature distribution **L2** of the comparative example which is shown by a dotted line is added as well. The piston surface temperature of the central area, in the radial direction, in the temperature distribution **L23** is considerably lowered compared to the temperature distribution **L2** of the comparative example. Further, this piston surface temperature is also lowered compared to the temperature distributions **L21, L22** shown in **FIGS. 14** and **15.** This is because the heat stored at the heat-insulation layer **71** is made to escape to the entire area of the piston body **50** except the arrangement portion of the heat-insulation layer **71.**

[0079] As described above, the piston surface temperature can be made to have the temperature distribution which is suitable for the slow combustion in the low-load engine operation by any of the combustion-chamber structures of the present embodiment. Meanwhile, it can be prevented in the middle/high-load engine operation that the piston surface temperature of the central area, in the radial direction, increases excessively. Accordingly, the increase of the cylinder internal temperature which may cause the preignitions **PIG** (FIG. **11**) can be prevented from occurring.

[Embodiments with Oil-Jet Cooling]

[0080] Other embodiments of the present invention will be described. FIG. **17A** is a sectional view of the piston **5-3** which shows another embodiment in a case where oil-jet cooling is applied. The piston body **50** of the piston **5-3** comprises one or more, particularly a pair of openings **507** which are provided to be connected to a pair of cooling recess portions **506,** respectively. A pair of penetration holes which penetrate the piston body **50** in the cylinder axial direction are provided by connection of the cooling recess portion **506** and the opening **507.**

[0081] A heat-insulation layer **71A** is provided on the upper surface **501** of the piston body **50** in an area between the pair of openings **507.** The opening **507** is provided at the long-diameter side ridgeline portion **52** of the cavity **5C.** Accordingly, the heat-insulation layer **71A** is provided at a position corresponding to the arrangement position of the cavity **5C.** A heat-diffusion layer **73C** is preferably provided to cover the entire area of the upper surface **501.** Further, the heat-diffusion layer **73C** comprises a seal portion **733** which seals the opening **507.** The seal portion **733** is configured to seal a part of the above-described penetration hole which is formed by the cooling recess portion **506** and the opening **507** near the upper surface **501** of the piston body **50.** The heat-insulation layer **72** is provided to cover an entire area, in the radial direction, of the heat-diffusion layer **73C.**

[0082] FIG. **17B** is a sectional view showing a state where cooling oil **81** is injected to a piston **5-3.** An oil jet nozzle **80** (oil jet device) to inject the cooling oil **81** is arranged below the piston **5-3.** The oil jet nozzle **80** injects the cooling oil **81** toward the seal portion **733** of the heat-diffusion layer **73C** from below the cooling recess portion **506** (penetration hole).

[0083] According to the combustion-chamber structure using the piston **5-3,** a contact portion between the heat-diffusion layer **73C** and the piston body **50** can be provided at a contact portion between an inner peripheral surface of the opening **507** and the seal portion **733.** That is, a heat-dissipation path of the heat of the heat-insulation layer **71Ato** the piston body **50** can be secured. Additionally, the heat-diffusion layer **73C** can be cooled by injecting the cooling oil **81** toward the seal portion **733** from the oil jet nozzle **80.** Accordingly, the excessive heat increase of the heat-barrier layer **72** can be prevented. Further, since the heat-insulation layer **71A** exits on the back-face side of the heat-barrier layer **72** in an area of the cavity **5C** where the fuel is injected from the injector **18** and thereby the temperature becomes high, the heat loss can be effectively suppressed.

[0084] FIG. **18** is a sectional view of a piston **5-4** which shows another embodiment in a case where the oil-jet cooling is applied. What is different from the piston **5-3** shown in FIG. **17A** is that a heat-insulation layer **71B** comprising an extension portion **712** which is positioned on the outward side, in the radial direction, of the opening **507** is used. In this embodiment as well, the contact portion between the heat-diffusion layer **73C** and the piston body **50** is the contact portion between the inner peripheral surface of the opening **507** and the seal portion **733.** According to this piston **5-4,** since the heat-insulation layer **71A** exits on the back-face side of the heat-barrier layer **72** in the entire area, in the radial direction, of the crown surface **5H,** the heat loss can be suppressed further more. Herein, what the cooling oil **81** is injected toward the seal portion **733** of the heat-diffusion layer **73C** from below the cooling recess portion **506** is the same as the case of the above-described piston **5-3,** illustration of which is omitted here.

[Operations/Effects]

[0085] According to the combustion-chamber structure of the engine of the above-described present embodiment, the heat transferred to the heat-insulation layer **71** is not stored at this heat-insulation layer **71** and thereby a structure to make the heat escape toward the piston body **50** can be provided. That is, the heat-diffusion layer **73** is formed between the heat-insulation layer **7** and the heat-barrier layer **72.** This heat-diffusion layer **73** has the larger heat conductivity than both the heat-insulation layer **71** and the heat-barrier layer **72** and comprises the contact portion (the side end edge **731** or the extension portion **732**) contacting with the piston body **50.** Accordingly, even if the heat-insulation layer **71** has stored the heat, this stored heat can be made to transfer to the piston body **50** through the heat-diffusion layer **73.** That is, the heat stored at the heat-insulation layer **71** can be made to escape to the piston body **50,** without being made to transfer to the heat-barrier layer **72.** Accordingly, the excessive temperature increase of the heat-barrier layer **72** in the middle/high-load engine operation, for example, is so suppressed that the increase of the cylinder internal temperature which may cause the preignition can be prevented properly.

[0086] Further, the heat-insulation layer **71** is located at the position which corresponds to the central area, in the radial direction, of the piston body **50** where the cavity **5C** is arranged. That is, the heat-insulation layer **71** is provided at the back-face side of the heat-barrier layer **72** in an area where the temperature of the piston **5** becomes high during the combustion. Accordingly, the temperature difference between the combustion gas inside the combustion chamber **6** and the heat-barrier layer **72** (crown surface **5H**) can be made as small as possible, so that the heat loss can be reduced properly. Meanwhile, since the heat of the heat-insulation layer **71** is made to escape to the piston body **50** via the heat-diffusion layer **73,** the temperature of the heat-barrier layer **72** can be prevented from increasing excessively.

Claims

1. A piston (5) for an engine including a combustion chamber (6) partitioned by a cylinder block (3), a cylinder head (4), and the piston (5), the piston (5) comprising:

    a piston body (50) which has an upper surface (501) facing the combustion chamber (6);
    a heat-insulation layer (71; 71A; 71B) which is provided at least in a central area, in a radial direction, of the upper surface (501) of the piston body (50) and has a heat conductivity smaller than a heat conductivity of the piston body (50);
    a heat-barrier layer (72) which is provided to cover the upper surface (501) of the piston (5) and has a heat conductivity smaller than the heat conductivity of the piston body (50) and the heat conductivity of the heat-insulation layer (71; 71A; 71B); and
    a heat-diffusion layer (73; 73A; 73B) which is provided between the heat-insulation layer (71; 71A; 71B) and the heat-barrier layer (72) and has a heat conductivity larger than the heat conductivity of the heat-insulation layer (71; 71A; 71B) and the heat conductivity of the heat-barrier layer (72), and
    wherein the heat-diffusion layer (73; 73A; 73B) comprises a contact portion which contacts with the piston body (50).

2. The piston (5) of claim 1, wherein the piston body (50) comprises a cavity (5C) which is concaved downwardly, in a cylinder axial direction, at the upper surface (501), and the cavity (5C) is located at a position which corresponds to the central area, in the radial direction, of the upper surface (501) of the piston (5).

3. The piston (5) of claim 1 or 2, wherein the heat-diffusion layer (73) comprises an extension portion (732) which extends outwardly, in the radial direction, from an outer peripheral edge (711) of the heat-insulation layer (71).

4. The piston (5) of claim 3, wherein the extension portion (732) is the contact portion which contacts with the piston body (50).

5. The piston (5) of any one of the preceding claims, wherein an outer peripheral edge (731B) of the heat-diffusion layer (73B) extends up to an outer peripheral edge (5E) of the upper surface (501) of the piston body (50).

6. The piston (5) of any one of the preceding claims, wherein the heat conductivity of the heat-barrier layer (72) is within a range of 0.05 - 1.50W/mK, and/or the heat conductivity of the heat-diffusion layer (73) is within a range of 35 - 600W/mK.

7. The piston (5) of any one of the preceding claims, wherein the heat-barrier layer (72) is made of heat-resistant silicon resin, and/or the heat-diffusion layer (73) is made of copper-based material, Corson alloy, beryllium copper, fiber-reinforced aluminum alloy, or titanium aluminum.

8. The piston (5) of any one of the preceding claims, wherein
    the heat-diffusion layer (73B; 73C) is provided to cover an entire part of an upper surface of the heat-insulation layer (71).

9. The piston (5) of any one of the preceding claims, wherein
    the heat-barrier layer (72) is provided to cover at least both of an entire part of an upper surface of the heat-diffusion layer (73; 73A; 73B; 73C) and an outside area, in the radial direction, of the upper surface (501) of the piston body (50).

10. The piston (5) of any one of the preceding claims, wherein
    the heat-diffusion layer (73B; 73C) is provided to cover both of an entire part of an upper surface of the heat-insulation layer (71) and an outside area, in the radial direction, of the upper surface (501) of the piston body (50)

11. The piston (5) of any one of the preceding claims, wherein
    the heat-barrier layer (72) is provided to cover an entire part of an upper surface of the heat-diffusion layer (73).

12. A combustion-chamber structure comprising the pis-

ton (5) of any one of the preceding claims.

13. The combustion-chamber structure of claim 12, further comprising an oil jet device (80) configured to inject cooing oil (81), wherein
the piston body (50) comprises a penetration hole (506) which penetrates the piston body (50) in the cylinder axial direction,
the heat-diffusion layer (73C) comprises a seal portion (733) configured to seal a part of the penetration hole (506) on or near the upper surface (501) of the piston body (50), and
the oil jet device (80) is configured to inject the cooling oil (81) from below the penetration hole (506) toward the seal portion of the heat-diffusion layer (73).

14. An engine comprising:

a cylinder block (3);
a cylinder head (4);
the piston (5) of nay one of claims 1 to 11 or the combustion-chamber structure of claim 12 or 13; and
a combustion chamber (6) partitioned by the cylinder block (3), the cylinder head (4), and the piston (5).

15. A vehicle comprising the engine of claim 14.

FIG. 1

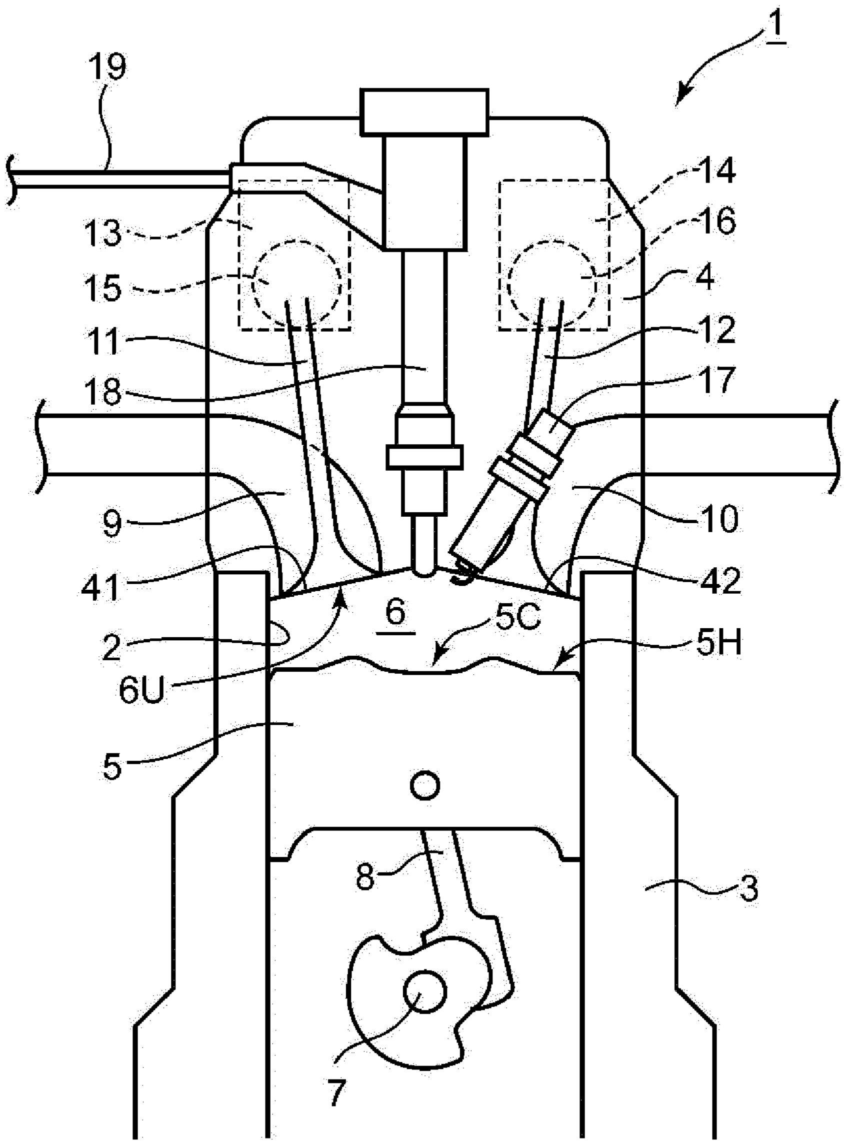


FIG. 2

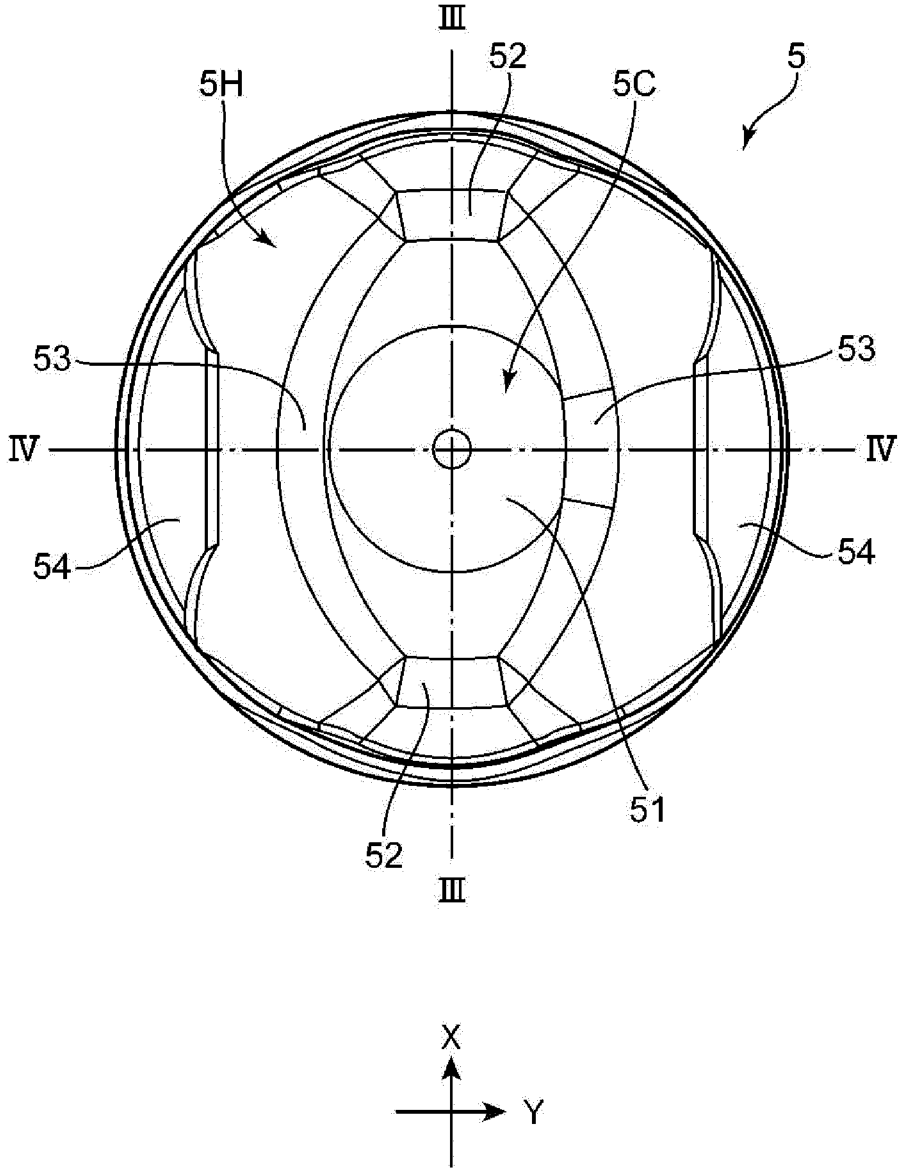


FIG. 3A

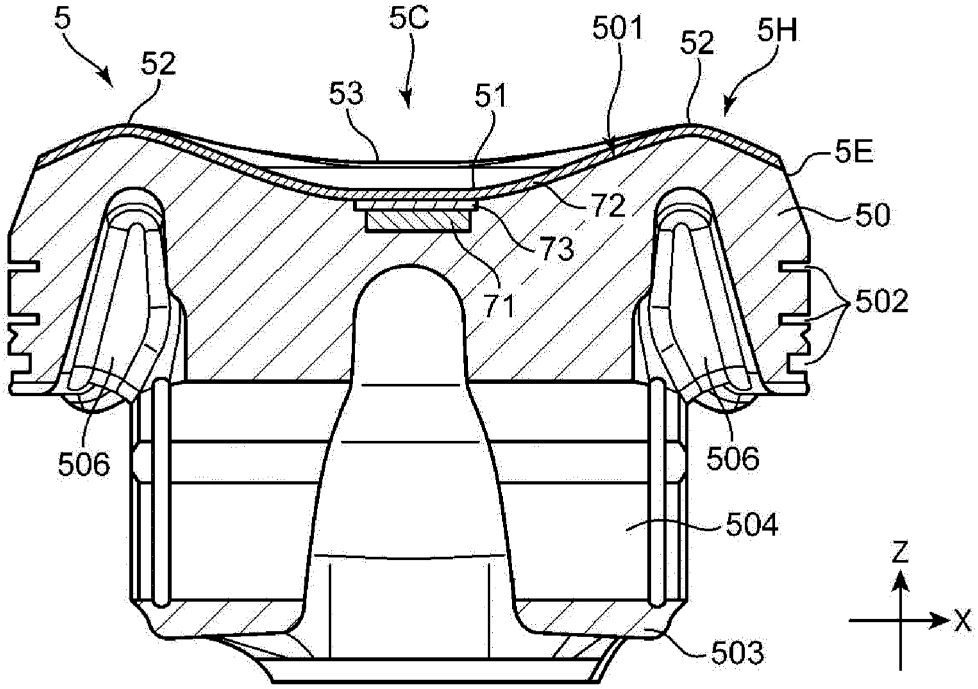

5
5C
501
52
5H
52
53
51
5E
72
50
73
71
502
506
506
504
Z
X
503

FIG. 3B

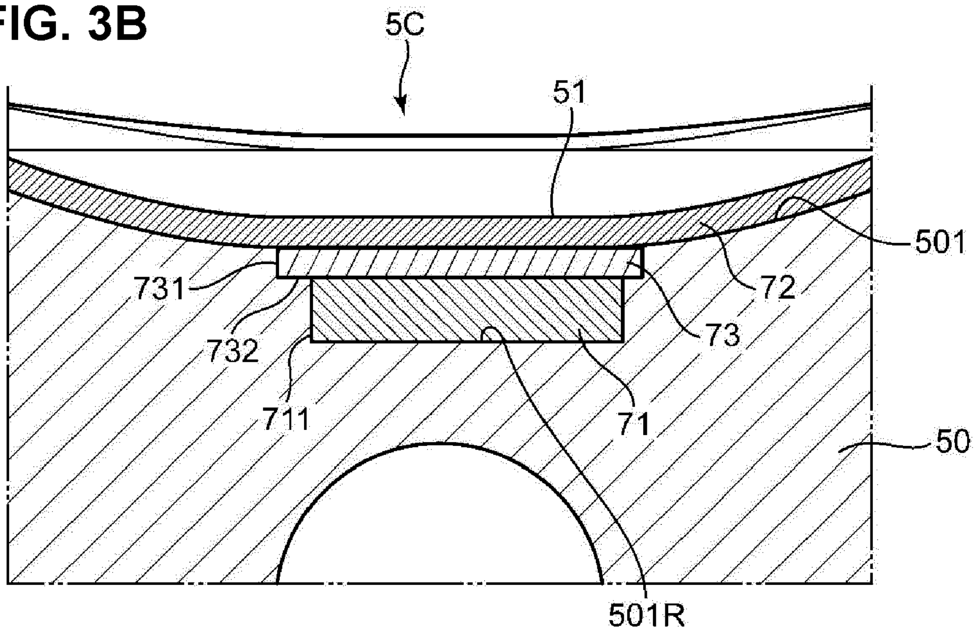

5C
51
501
731
72
732
73
711
71
50
501R

FIG. 4

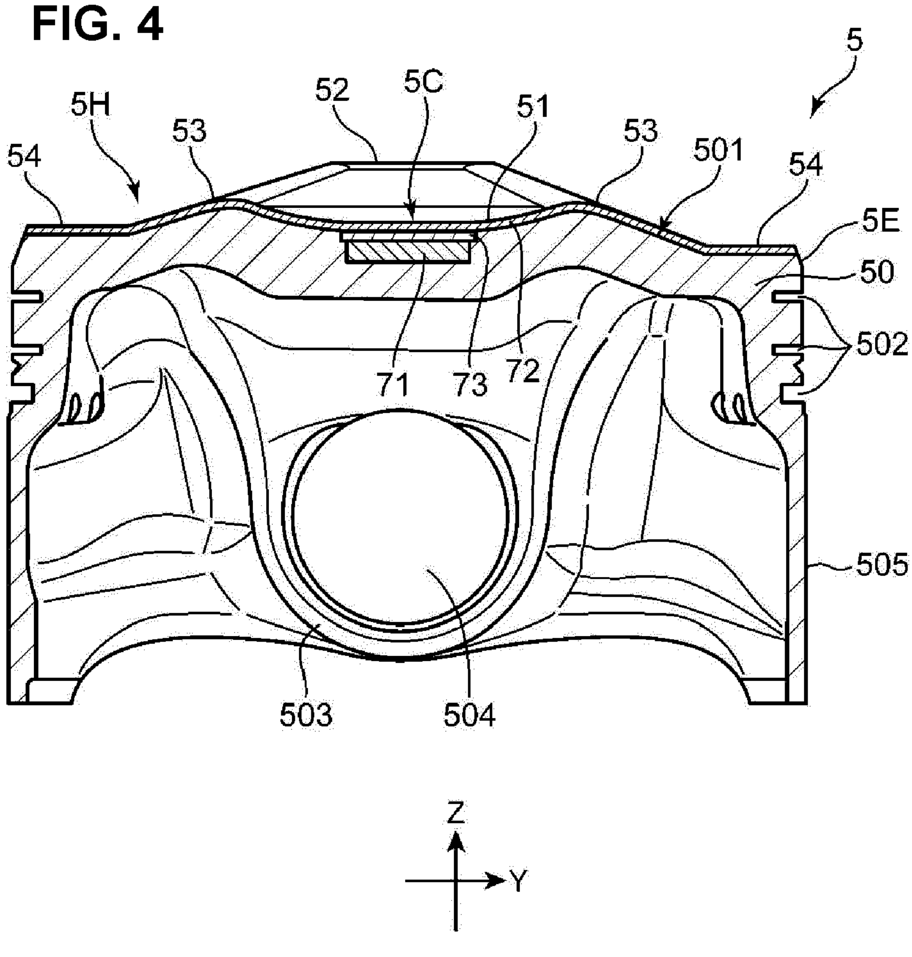


FIG. 5

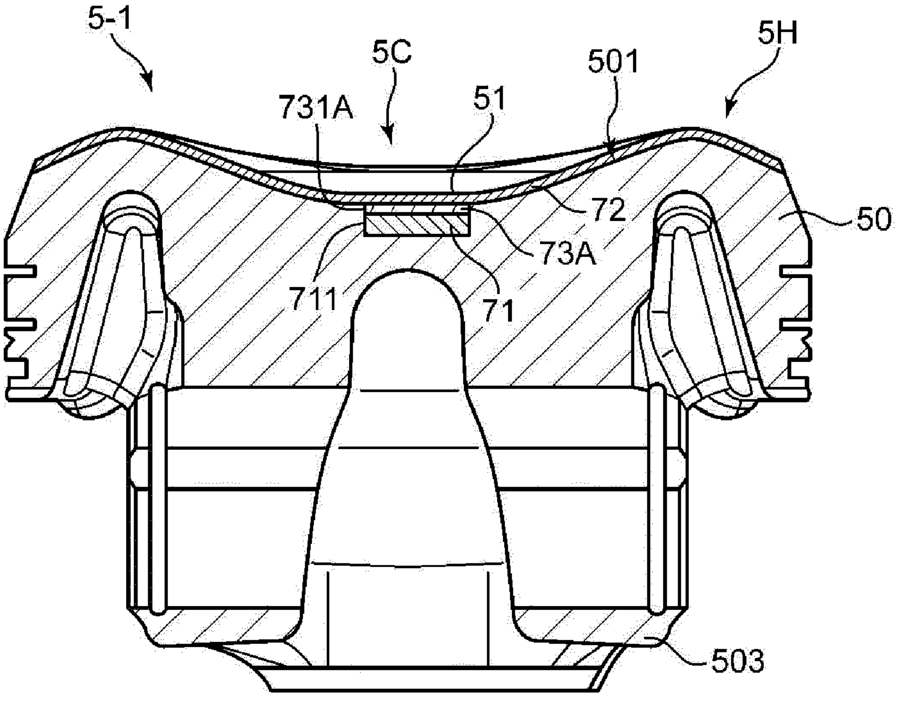


FIG. 6

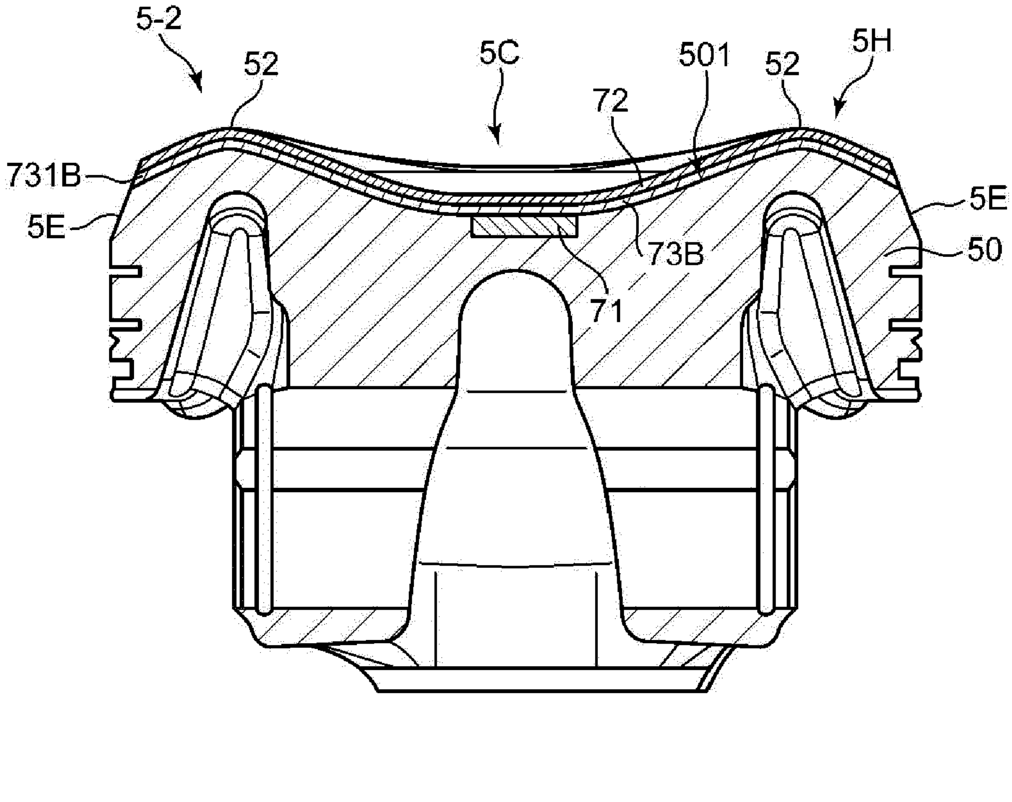


FIG. 7

		heat conductivity λ	volume specific heat ρc	heat diffusivity λ/ρc		Z-directional thickness t (mm)	heat resistance t/λ	heat permeability √λρc
heat-barrier layer		0.2	1000	0.0002	1	0.075	0.3750	14
heat-diffusion layer	Cu based material	400	3500	0.1143	571	2	0.0050	1183
	Corson alloy	239	3349.5	0.0714	357	2	0.0084	895
	beryllium copper	125	3460	0.0361	181	2	0.0160	658
	fiber-reinforced aluminum	100	3120	0.0321	160	2	0.0200	559
	titanium aluminum	40	2340	0.0171	85	2	0.0050	306
heat-insulation layer	calcium silicate	0.24	2000	0.00012	0.6	2	8.3333	22
	ZrO_2 zirconia	3	2576	0.0012	6	2	0.6667	88
	porous SUS based material	5	2352	0.0021	11	3.5	0.7000	108
	↑(relative density: large)	8	2970	0.0027	13	5	0.6250	154
cylinder block/head base material	AC4B	96	2667	0.0360	180	6	0.0625	506
piston base material	AC8A	125	2600	0.0481	240	4	0.0320	570
intake valve base material	SUH11	25	3850	0.0065	32	4	0.1600	310
exhaust valve base material	SUH35	18	3565	0.0050	25	4	0.2222	253
		(W/mK)	($kJ/m^3 \cdot K$)				($m^2 \cdot K/W$)	

FIG. 8

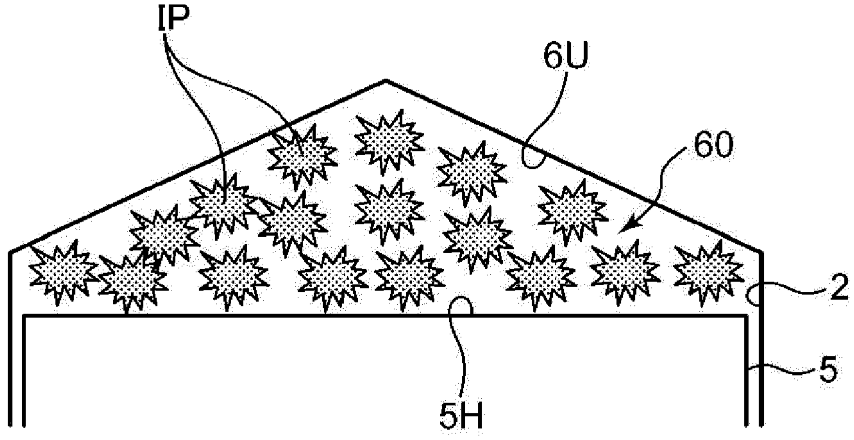


FIG. 9

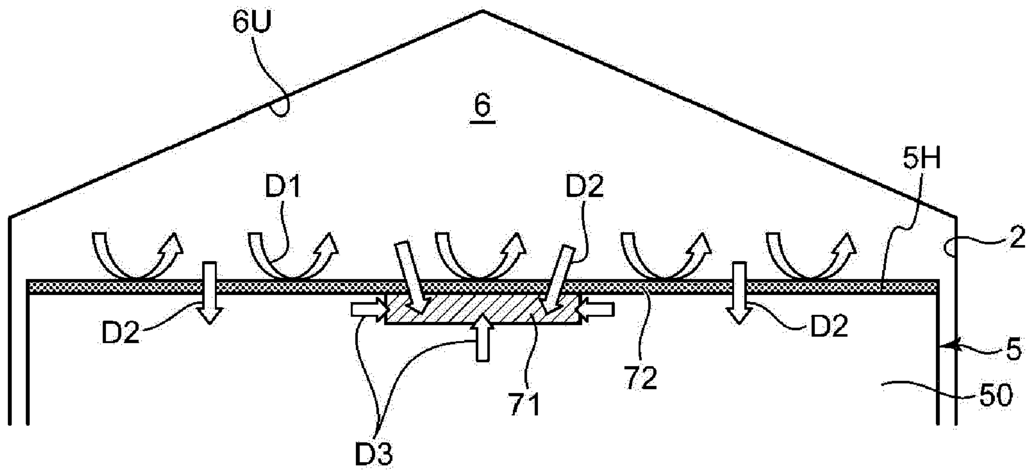


FIG. 10

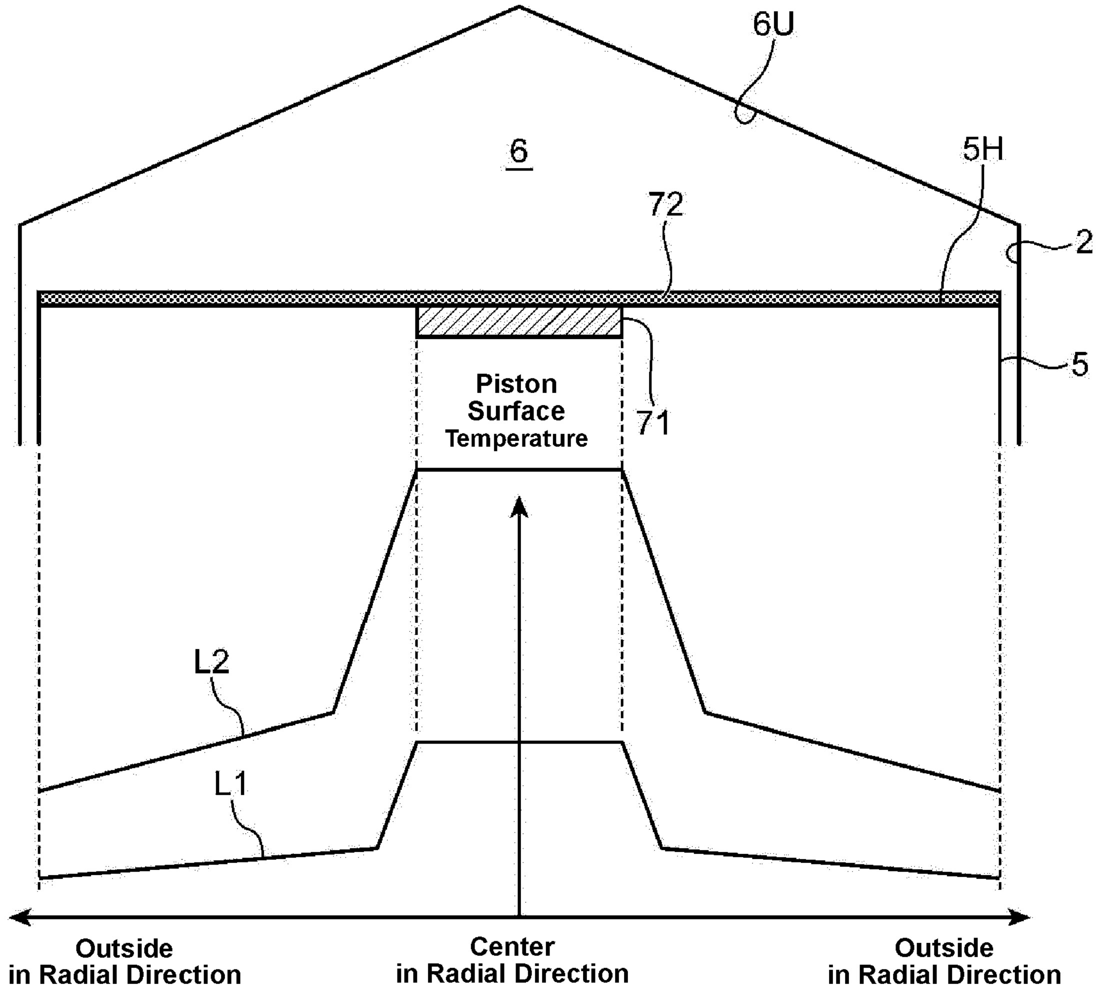

6U
6
5H
72
2
5
Piston
Surface
Temperature
71
L2
L1
Outside
in Radial Direction
Center
in Radial Direction
Outside
in Radial Direction

FIG. 11

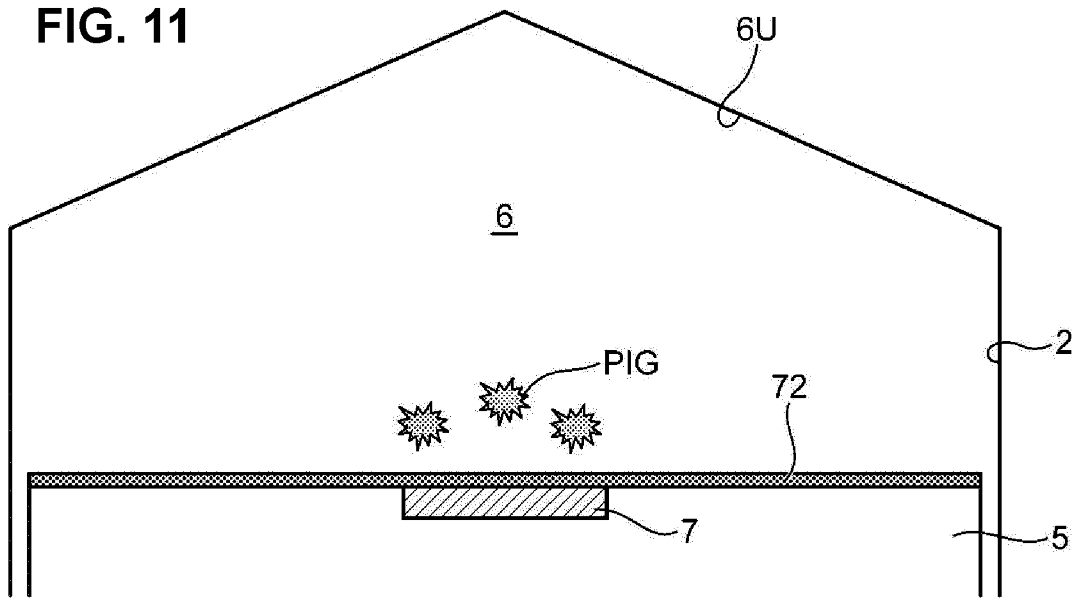

6U
6
2
PIG
72
7
5

FIG. 12A

Low-Load Engine Operation

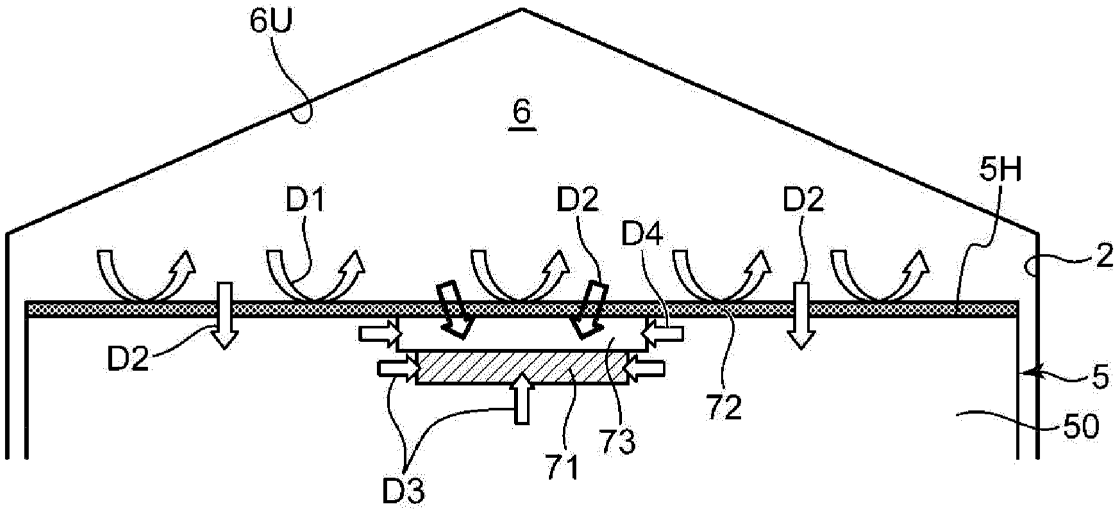
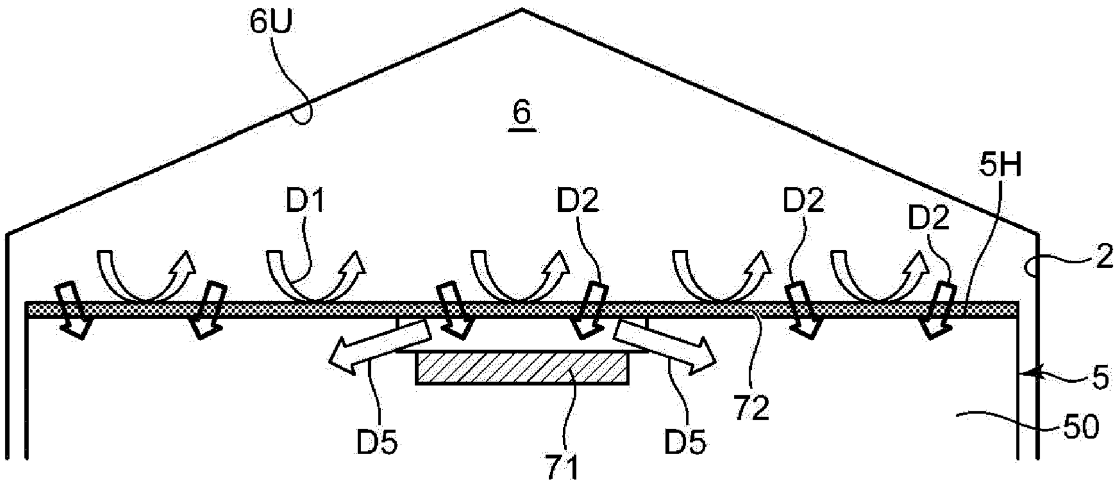


FIG. 12B

Middle/High-Load Engine Operation



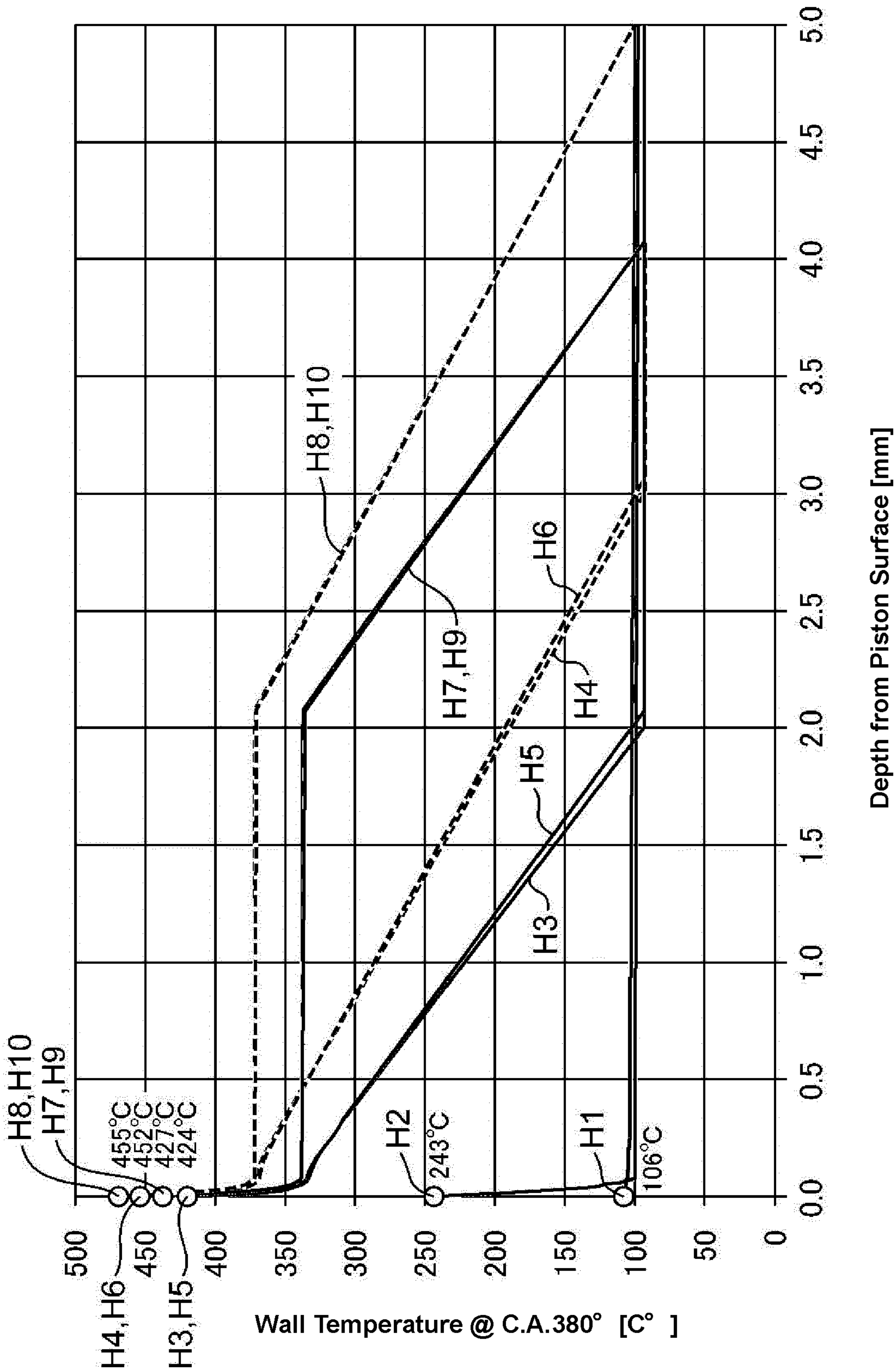

Wall Temperature @ C.A.380° [C°]
Depth from Piston Surface [mm]
500
450
400
350
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
H8,H10
H7,H9
455°C
452°C
427°C
424°C
H4,H6
H3,H5
H2
243°C
H1
106°C
H3
H5
H4
H6
H7,H9
H8,H10

FIG. 13

FIG. 14

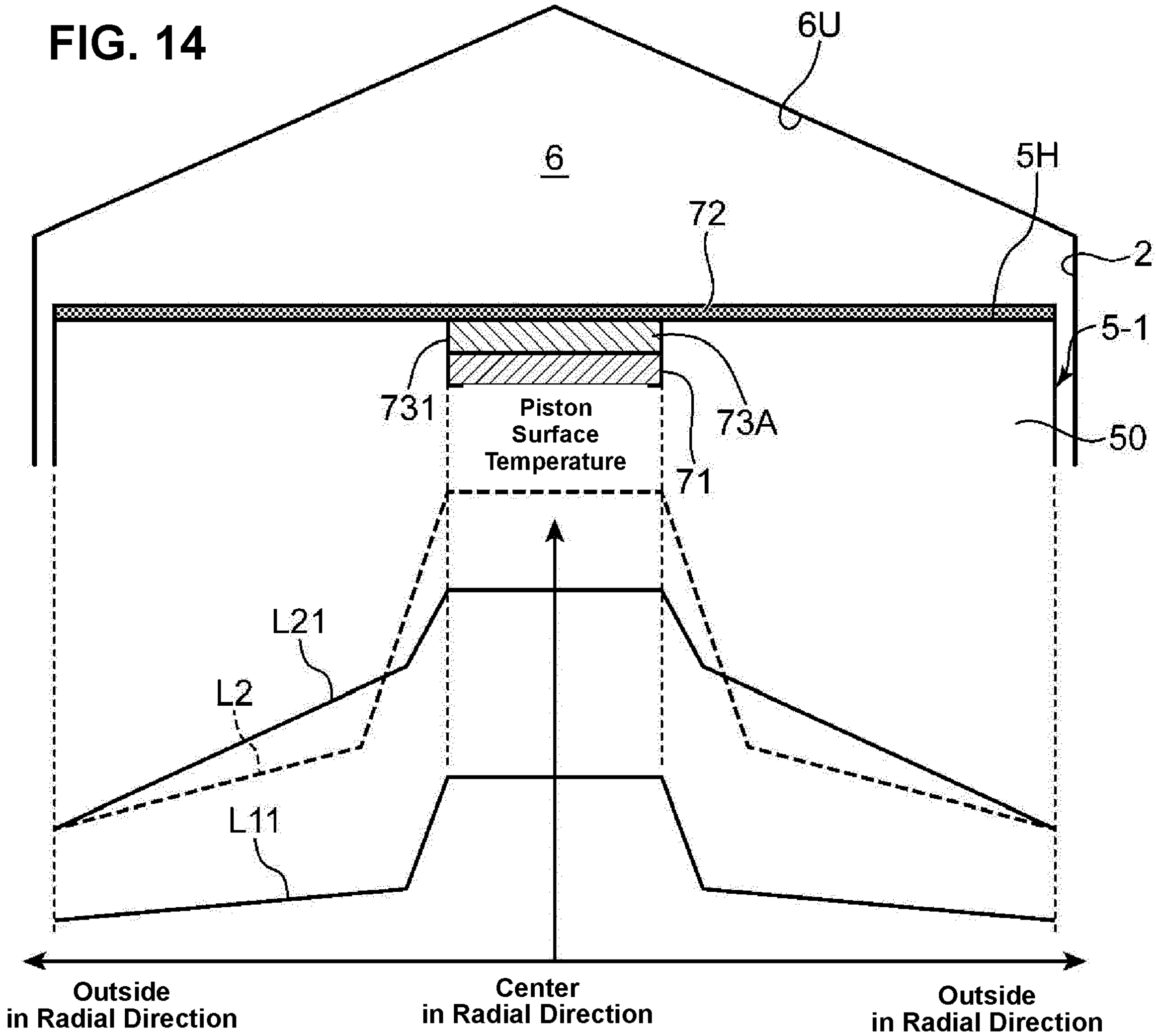

6U
6
5H
72
2
5-1
731
Piston
Surface
Temperature
73A
50
71
L21
L2
L11
Outside
in Radial Direction
Center
in Radial Direction
Outside
in Radial Direction

FIG. 15

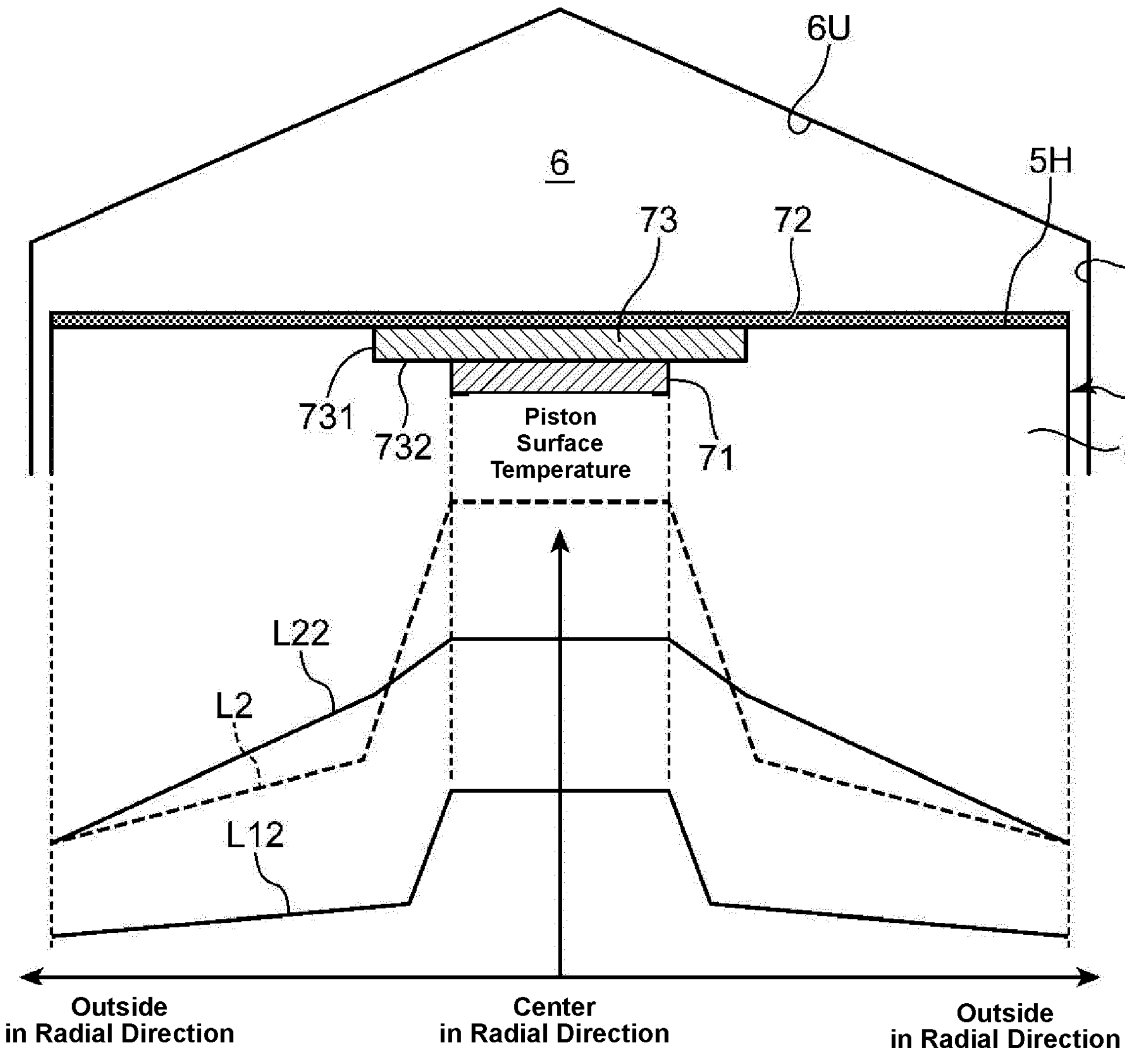

6U
6
5H
73
72
2
731
732
71
5
50
Piston
Surface
Temperature
L22
L2
L12
Outside
in Radial Direction
Center
in Radial Direction
Outside
in Radial Direction

FIG. 16

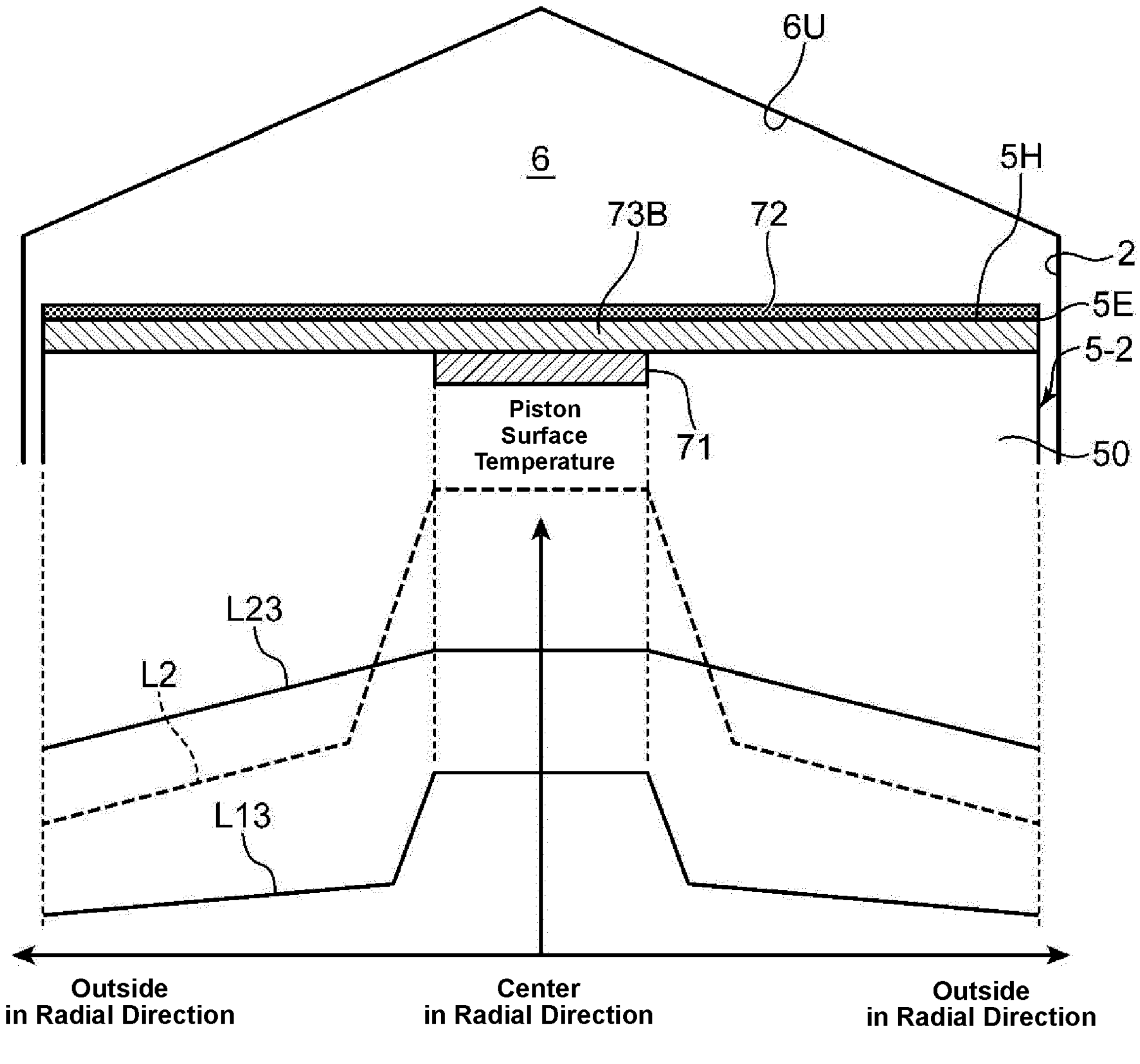

6U
6
5H
73B
72
2
5E
5-2
Piston
Surface
Temperature
71
50
L23
L2
L13
Outside
in Radial Direction
Center
in Radial Direction
Outside
in Radial Direction

FIG. 17A

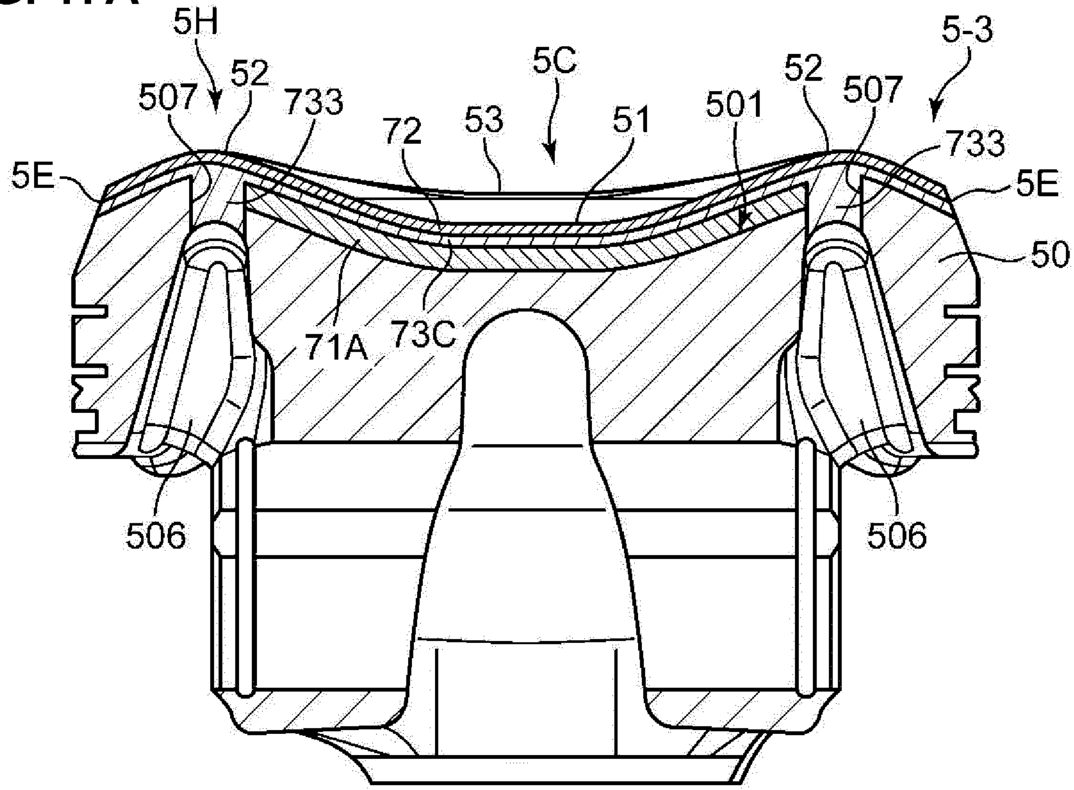


FIG. 17B

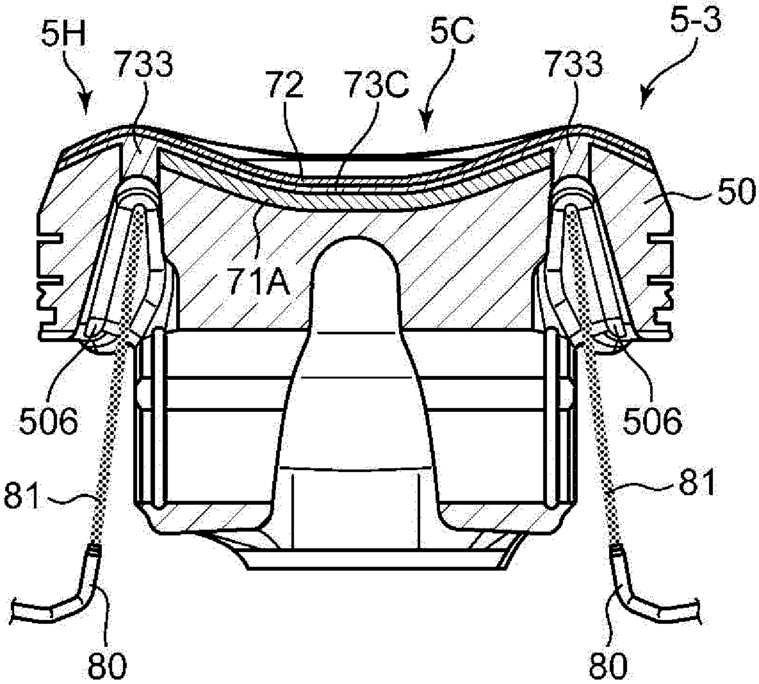
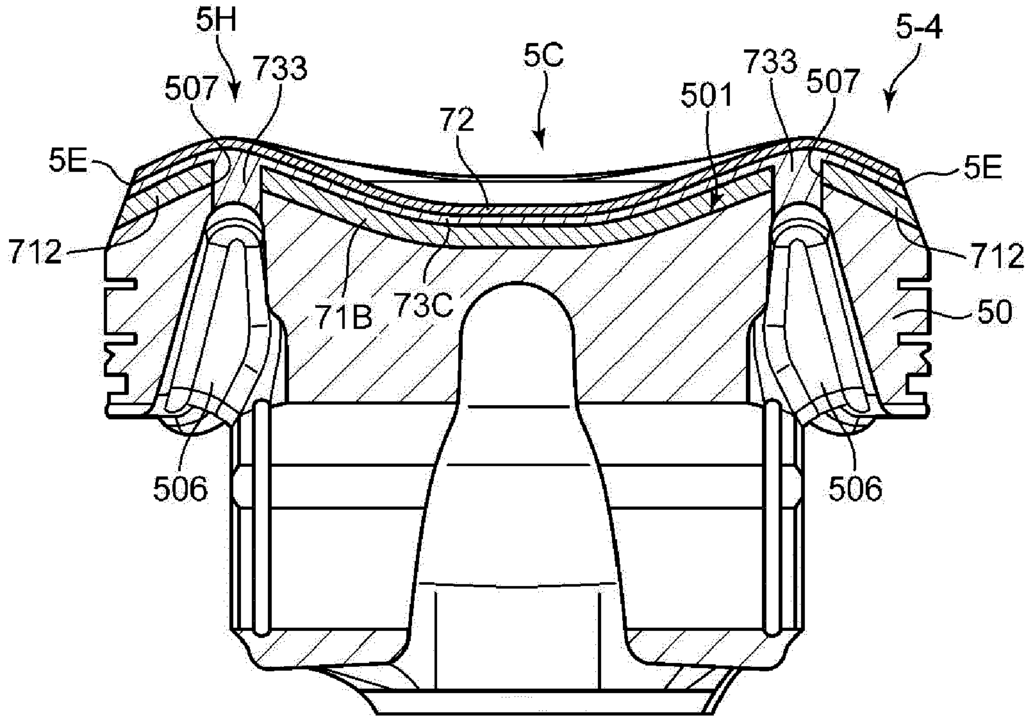


FIG. 18



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EUROPEAN SEARCH REPORT

Application Number
EP 21 15 9445

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A	SU 964 211 A1 (KH POLT I IM V I LENINA [SU]) 7 October 1982 (1982-10-07) * figures * -----	1-15	INV. F02F3/14
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	4 August 2021	Matray, J

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