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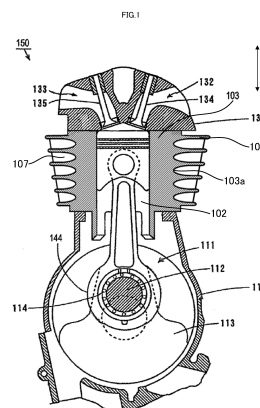
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(54) **AIR-COOLED ENGINE, CYLINDER BODY MEMBER FOR AIR-COOLED ENGINE, AND VEHICLE EQUIPPED WITH AIR-COOLED ENGINE**

(57) An object of the present teaching is to provide an air-cooled engine that is able to improve cooling efficiency, and particularly cooling efficiency at a time of initial sliding of a piston part. The present teaching provides an air-cooled engine including a piston part and a cylinder body part with a sliding surface on which the piston part is slidable. The cylinder body part includes a heat dissipation portion provided on an outer surface of the cylinder body part, and is made of an Al-containing metal. At least an inner peripheral portion of the cylinder body part, which includes the sliding surface, is made of an Al alloy with an Si content of 16% by mass or more. The sliding surface is configured such that a plurality of substantially parallel linear grooves are formed therein and Si primary crystal grains having an average crystal grain diameter of 8 μm or more and 50 μm or less are exposed thereon so as to be contactable with the piston part. An Al contact portion where an Al alloy base material has contact with the piston part, which is formed between the plurality of

linear grooves, is exposed on the sliding surface at a location between two adjacent Si primary crystal grains. Al contained in the cylinder body part is physically continuous from the Al contact portion to the heat dissipation portion.



Description

Technical Field

[0001] The present teaching relates to an air-cooled engine, a cylinder body member for an air-cooled engine, and a vehicle including an air-cooled engine.

Background Art

[0002] An air-cooled engine is an engine configured such that heat generated in the engine is discharged by using air to cool the engine. The air-cooled engine, in general, has a relatively simple structure as compared with a water-cooled engine. The air-cooled engine is therefore robust and easy-to-maintain. The air-cooled engine, however, has a cooling efficiency lower than the cooling efficiency of the water-cooled engine. Heat in the engine may undesirably cause distortion of a cylinder body part. This is why improvement in the cooling efficiency is desired in the air-cooled engine.

[0003] In the air-cooled engine, normally, heat of the engine is dissipated by blowing an outer surface (for example, a heat dissipation fin) of the cylinder body part. Conventionally, various measures have been devised for the cooling of the air-cooled engine (for example, see Patent Literatures 1 to 3 (PTLs 1 to 3)).

[0004] Patent Literature 1 shows an air-cooled engine in which an oil passage connected to an oil pump for injecting a lubricant is formed in an outer wall of a cam chain chamber. The lubrication oil is injected through the oil passage toward an outer wall of a cylinder. Patent Literatures 2 and 3 show air-cooled engines configured such that a lubricant flows down a wall portion of a cylinder block after the lubricant lubricates a valve train arranged in a valve chamber within a cylinder head.

Citation List

Patent Literature

[0005] PTL 1 : Japanese Patent Application Laid-Open No. 1996-260960 PTL 2 : Japanese Patent Application Laid-Open No. 1998-54296 PTL 3 : Japanese Patent Application Laid-Open No. 1999-101112

Summary of the Invention

Technical Problem

[0006] An object of the present teaching is to provide an air-cooled engine, a cylinder body member for an air-cooled engine, and a vehicle including an air-cooled engine that are able to improve cooling efficiency, and particularly cooling efficiency at a time of initial sliding of a piston part.

Solution to Problem

[0007] The present teaching can adopt the following configurations.

[0008] (1) An air-cooled engine including a piston part and a cylinder body part with a sliding surface on which the piston part is slidable, the cylinder body part including a heat dissipation portion provided on an outer surface of the cylinder body part, the cylinder body part being made of an Al-containing metal, at least an inner peripheral portion of the cylinder body part being made of an Al alloy with an Si content of 16% by mass or more, the inner peripheral portion including the sliding surface, the sliding surface being configured such that a plurality of substantially parallel linear grooves are formed therein and Si primary crystal grains are exposed thereon so as to be contactable with the piston part, the Si primary crystal grains having an average crystal grain diameter of 8 μm or more and 50 μm or less, the sliding surface having an Al contact portion exposed thereon at a location between two adjacent Si primary crystal grains, the Al contact portion being formed between the plurality of linear grooves, the Al contact portion being a portion where an Al alloy base material has contact with the piston part, Al in the cylinder body part being physically continuous from the Al contact portion to the heat dissipation portion.

[0009] In the configuration of (1), the cylinder body part is made of an Al-containing metal, and at least the inner peripheral portion of the cylinder body part, which includes the sliding surface, is made of an Al alloy with an Si content of 16% by mass or more. The average crystal grain diameter of the Si primary crystal grains is 8 μm or more and 50 μm or less. In the sliding surface, the plurality of substantially parallel linear grooves are formed, and the Si primary crystal grains are exposed so as to be contactable with the piston part. In consideration of receiving a load from the piston part, the Si primary crystal grains are given appropriate sizes and distributed appropriately over the sliding surface. Under such conditions, the Al contact portion is exposed on the sliding surface at a location between two adjacent Si primary crystal grains such that the Al contact portion is contactable with the piston part. Thus, the Si primary crystal grains, which have a higher hardness than the hardness of the Al contact portion, receive a load from the piston part. As a result, a load applied from the piston part to the Al contact portion is likely to be reduced. Since the plurality of substantially parallel linear grooves are formed in the sliding surface, balanced retention of a lubricant on the sliding surface is achieved, thus improving uniformity of dispersion of the lubricant on the sliding surface. The Al contact portion is formed between the plurality of linear grooves under such conditions, and therefore the lubricant is easily supplied onto a surface of the Al contact portion. For the reasons above, the configuration of (1) is able to allow the Al contact portion to have contact with the piston part

while suppressing generation of scuffs which otherwise can be generated by sliding of the piston part on the Al contact portion. Al contained in the cylinder body part is physically continuous from the Al contact portion to the heat dissipation portion (for example, a heat dissipation fin) provided on the outer surface of the cylinder body part. That is, the cylinder body part has a heat transfer path made of Al that continuously extends from the Al contact portion to the heat dissipation portion. This allows heat that the Al contact portion receives from the piston part to be efficiently transferred from the Al contact portion to the heat dissipation portion and emitted from the heat dissipation portion. As a result, cooling efficiency of the air-cooled engine, and particularly cooling efficiency at a time of initial sliding of the piston part, can be improved. In the initial sliding of the piston part, permeation of the lubricant on the sliding surface can be insufficient. When cooling efficiency is not sufficient, distortion of the cylinder body part or generation of scuffs in the sliding surface may be caused by a temperature rise. This is why cooling efficiency at a time of initial sliding of the piston part is important in the air-cooled engine.

[0010] (2) An air-cooled engine including a piston part and a cylinder body part with a sliding surface on which the piston part is slidable, the cylinder body part including a heat dissipation portion provided on an outer surface of the cylinder body part, the cylinder body part being made of an Al-containing metal, at least an inner peripheral portion of the cylinder body part being made of an Al alloy with an Si content of 16% by mass or more and formed by a high-pressure die casting process, the inner peripheral portion including the sliding surface, the sliding surface being configured such that a plurality of substantially parallel linear grooves are formed therein and Si primary crystal grains are exposed thereon so as to be contactable with the piston part, the sliding surface having an Al contact portion exposed thereon at a location between two adjacent Si primary crystal grains, the Al contact portion being formed between the plurality of linear grooves, the Al contact portion being a portion where an Al alloy base material has contact with the piston part, Al in the cylinder body part being physically continuous from the Al contact portion to the heat dissipation portion.

[0011] In the configuration of (2), the cylinder body part is made of an Al-containing metal, and at least the inner peripheral portion of the cylinder body part, which includes the sliding surface, is made of an Al alloy with an Si content of 16% by mass or more and formed by a high-pressure die casting process. In the sliding surface, the plurality of substantially parallel linear grooves are formed, and the Si primary crystal grains are exposed so as to be contactable with the piston part. In consideration of receiving a load from the piston part, the Si primary crystal grains are given appropriate sizes and distributed appropriately over the sliding surface. Under such conditions, the Al contact portion is exposed on the sliding

surface at a location between two adjacent Si primary crystal grains such that the Al contact portion is contactable with the piston part. Thus, the Si primary crystal grains, which have a higher hardness than the hardness of the Al contact portion, receive a load from the piston part. As a result, a load applied from the piston part to the Al contact portion is likely to be reduced. Since the plurality of substantially parallel linear grooves are formed in the sliding surface, balanced retention of a lubricant on the sliding surface is achieved, thus improving the uniformity of dispersion of the lubricant on the sliding surface. The Al contact portion is formed between the plurality of linear grooves under such conditions, and therefore the lubricant is easily supplied onto a surface of the Al contact portion. For the reasons above, the configuration of (2) is able to allow the Al contact portion to have contact with the piston part while suppressing generation of scuffs which otherwise can be generated by sliding of the piston part on the Al contact portion. Al contained in the cylinder body part is physically continuous from the Al contact portion to the heat dissipation portion (for example, a heat dissipation fin) provided on the outer surface of the cylinder body part. That is, the cylinder body part has a heat transfer path made of Al that continuously extends from the Al contact portion to the heat dissipation portion. This allows heat that the Al contact portion receives from the piston part to be efficiently transferred from the Al contact portion to the heat dissipation portion and emitted from the heat dissipation portion. As a result, cooling efficiency of the air-cooled engine, and particularly cooling efficiency at a time of initial sliding of the piston part, can be improved.

[0012] (3) The air-cooled engine of (1) or (2), in which a portion of the cylinder body part other than the inner peripheral portion is provided with the heat dissipation portion, physically continuous with the inner peripheral portion, and made of an Al alloy having an Si content equal to or less than the Si content in the inner peripheral portion, and

the Al alloy base material included in the cylinder body part is physically continuous from the Al contact portion to the heat dissipation portion.

[0013] In the configuration of (3), the Al alloy base material is physically continuous from the Al contact portion to the heat dissipation portion. That is, the cylinder body part has a heat transfer path made of the Al alloy base material and continuously extending from the Al contact portion to the heat dissipation portion. This allows heat that the Al contact portion receives from the piston part to be efficiently transferred from the Al contact portion to the heat dissipation portion and emitted from the heat dissipation portion. As a result, cooling efficiency of the air-cooled engine, and particularly cooling efficiency at a time of initial sliding of the piston part, can be improved.

[0014] (4) The air-cooled engine of any one of (1) to (3), in which the Al contact portion is exposed on the sliding surface at a location between two adjacent Si primary crystal

grains, and the Al contact portion is formed integrally with the heat dissipation portion.

[0015] In the configuration of (4), the Al alloy base material is physically continuous from the Al contact portion to the heat dissipation portion. That is, the cylinder body part has a heat transfer path made of the Al alloy base material and continuously extending from the Al contact portion to the heat dissipation portion. This allows heat that the Al contact portion receives from the piston part to be efficiently transferred from the Al contact portion to the heat dissipation portion and emitted from the heat dissipation portion. As a result, cooling efficiency of the air-cooled engine, and particularly cooling efficiency at a time of initial sliding of the piston part, can be improved.

[0016] (5) The air-cooled engine of any one of (1) to (4), in which

the plurality of linear grooves are formed at such a pitch that a plurality of linear grooves exist between the Si primary crystal grains.

[0017] The configuration of (5), in which the plurality of linear grooves are formed at a narrow pitch, enables a lubricant to be retained in a balanced manner between the Si primary crystal grains. This can improve the uniformity of dispersion of the lubricant on the sliding surface, and thus can enhance uniformity of an oil film formed on the sliding surface. Accordingly, wear, etc., of the Al contact portion can be suppressed effectively. It is possible to allow the Al contact portion to have contact with the piston part while suppressing generation of scuffs. Heat that the Al contact portion receives from the piston part can be more efficiently transferred from the Al contact portion to the heat dissipation portion and emitted from the heat dissipation portion. As a result, the cooling efficiency of the air-cooled engine, and particularly the cooling efficiency at a time of initial sliding of the piston part, can be further improved.

[0018] (6) The air-cooled engine of (5), in which the pitch is less than the average crystal grain diameter of the Si primary crystal grains.

[0019] In the configuration of (6), the plurality of substantially parallel linear grooves are formed at a narrower pitch. The uniformity of dispersion of the lubricant is further enhanced. As a result, the cooling efficiency of the air-cooled engine, and particularly the cooling efficiency at a time of initial sliding of the piston part, can be still further improved.

[0020] (7) The air-cooled engine of any one of (1) to (4), in which

the cylinder body part includes Si eutectic crystal grains in addition to the Si primary crystal grains and the Al alloy base material, the Si eutectic crystal grains having an average crystal grain diameter less than the average

crystal grain diameter of the Si primary crystal grains, and

the plurality of linear grooves have a depth equal to or more than one-third of an upper limit value of a diameter range of the Si eutectic crystal grains in a grain size distribution of Si crystal grains in the cylinder

body part, the plurality of linear grooves being formed at a pitch greater than the average crystal grain diameter of the Si primary crystal grains at least in an upper quarter region of the sliding surface, the plurality of linear grooves having a portion that exists between adjacent ones of the Si primary crystal grains.

[0023] In the configuration of (7), the plurality of substantially parallel linear grooves are formed at a pitch greater than the average crystal grain diameter of the Si primary crystal grains, and therefore the uniformity of dispersion of the lubricant on the sliding surface can be improved. As a result, the uniformity of the oil film formed on the sliding surface can be enhanced. In addition, a sufficient amount of lubricant can be retained in the grooves, because the plurality of linear grooves have a depth equal to or more than one-third of an upper limit value of a diameter range of the Si eutectic crystal grains in a grain size distribution of Si crystal grains in the cylinder body part. Accordingly, discontinuity of the oil film on the sliding surface can be suppressed. Furthermore, the plurality of linear grooves have a portion that extends between adjacent ones of the Si primary crystal grains. Since a load of the piston part is received by the Si primary crystal grains, wear of the sliding surface (the Al alloy base material) is suppressed in its regions near both sides of the groove, so that the retention of the lubricant in the groove is facilitated. In this manner, the configuration of (7) is able to enhance the uniformity of the oil film formed on the sliding surface, and also enables a sufficient amount of lubricant to be retained. Accordingly, wear, etc., of the Al contact portion can be suppressed effectively. It is possible to allow the Al contact portion to have contact with the piston part while suppressing generation of scuffs. Heat that the Al contact portion receives from the piston part can be more efficiently transferred from the Al contact portion to the heat dissipation portion and emitted from the heat dissipation portion. As a result, the cooling efficiency of the air-cooled engine, and particularly the cooling efficiency at a time of initial sliding of the piston part, can be further improved.

[0024] (8) The air-cooled engine of (7), in which the plurality of linear grooves have a depth equal to or more than one-third of an upper limit value of a diameter range of the Si eutectic crystal grains and less than the upper limit value of the diameter range of the Si eutectic crystal grains, in a grain size distribution of Si crystal grains in the cylinder body part.

[0025] The configuration of (8) enables a sufficient and appropriate amount of lubricant to be retained in the plurality of linear grooves. Thus, the uniformity of the oil film is further improved. As a result, the cooling efficiency of the air-cooled engine, and particularly the cooling efficiency at a time of initial sliding of the piston part, can be still further improved.

[0026] (9) The air-cooled engine of (7) or (8), in which the piston part includes a piston main body and a piston ring part, the piston ring part including a plurality of piston rings arranged on an outer periphery of the piston main

body, and

[0027] the plurality of linear grooves are formed at a pitch that is greater than the average crystal grain diameter of the Si primary crystal grains and less than the distance from a lower end of the piston ring part to an upper end of the piston ring part with respect to a reciprocating direction of the piston part.

[0028] The configuration of (9) enables a sufficient and appropriate amount of lubricant to be retained in the plurality of linear grooves. Thus, the uniformity of the oil film is further improved. As a result, the cooling efficiency of the air-cooled engine, and particularly the cooling efficiency at a time of initial sliding of the piston part, can be still further improved.

[0029] (10) The air-cooled engine of any one of (1) to (9), in which the Si primary crystal grains exposed on the sliding surface are at least partially broken down, and a surface appearing on the Si primary crystal grain as a result of the breakdown is exposed on the sliding surface.

[0030] In the configuration of (10), a surface (hereinafter referred to as a fracture surface) appearing on the Si primary crystal grain as a result of the breakdown functions as an oil reservoir. Since the fracture surface of the Si primary crystal grain is textured, the oil reservoir is capable of retaining a large amount of lubricant. The open area of the oil reservoir is, for example, comparable with the cross-sectional area of the Si primary crystal grain. The depth of the oil reservoir is, for example, less than the diameter of the Si primary crystal grain. Not only the plurality of substantially parallel linear grooves but also the oil reservoirs including the fracture surfaces of the Si primary crystal grains are formed in the sliding surface. This enables an increased amount of lubricant to be retained while maintaining the uniformity of dispersion of the lubricant. As a result, the cooling efficiency of the air-cooled engine, and particularly the cooling efficiency at a time of initial sliding of the piston part, can be still further improved.

[0031] (11) A cylinder body member provided with the cylinder body part included in the air-cooled engine of any one of (1) to (10).

[0032] The configuration of (11) achieves a cylinder body member that is able to improve cooling efficiency, and particularly cooling efficiency at a time of initial sliding of the piston part.

[0033] (12) A vehicle including the air-cooled engine of any one of (1) to (10).

[0034] The configuration of (12) achieves a vehicle including an air-cooled engine that is able to improve cooling efficiency, and particularly cooling efficiency at a time of initial sliding of the piston part.

Advantageous Effects of the Invention

[0035] The present teaching achieves improvement in cooling efficiency, and particularly cooling efficiency at a time of initial sliding of a piston part.

Brief Description of the Drawings

[0036] [Fig. 1] A cross-sectional view schematically showing an air-cooled engine 150 according to a first embodiment.

[Fig. 2] A side view schematically showing a piston part 122 included in the air-cooled engine 150 according to the first embodiment.

[Fig. 3] A plan view schematically showing, on an enlarged scale, a portion of a sliding surface 101 of a cylinder body part 100 according to the first embodiment.

[Fig. 4] A cross-sectional view schematically showing, on an enlarged scale, a portion of the sliding surface 101 of the cylinder body part 100 according to the first embodiment.

[Fig. 5] A graph showing a preferred example of a grain size distribution of Si crystal grains.

[Fig. 6] A plan view schematically showing, on an enlarged scale, a portion of a sliding surface 101 of a cylinder body part 100 according to a second embodiment.

[Fig. 7] (a) and (b) are cross-sectional views each schematically showing, on an enlarged scale, a portion of the sliding surface 101 of the cylinder body part 100 according to the second embodiment.

[Fig. 8] A side view schematically showing a motorcycle including the air-cooled engine 150 shown in Fig. 1.

Description of Embodiments

[0037] The inventors of the present teaching have conducted intensive studies for improving cooling efficiency of an air-cooled engine, and focused on the fact that Al has a high thermal conductivity. Al, though having high thermal conductivity, is vulnerable to generation of scuffs when having contact with a piston part during reciprocating motion of the piston part. For this reason, an air-cooled engine including a cylinder body part made of an Al-containing metal is conventionally configured to avoid contact of a piston part with an Al part. For example, conventionally in a cylinder body part made of an Al alloy with a relatively high Si content and manufactured by a high-pressure die casting process, a sliding surface is processed such that Si primary crystal grains are exposed in the form of floating islands. On the sliding surface, contact between a piston ring and an Al alloy base material is suppressed, and recesses each formed between the Si crystal grains function as oil reservoirs. This is how generation of scuffs is suppressed.

[0038] The inventors of the present teaching have conducted intensive studies for improving the cooling efficiency of an air-cooled engine, to reach the following findings.

[0039] In a cylinder body part made of an Al alloy with a relatively high Si content and manufactured by a high-

pressure die casting process, in consideration of receiving a load from a piston part, Si primary crystal grains are given appropriate sizes and distributed appropriately over a sliding surface. Balanced retention of a sufficient amount of lubricant between the Si primary crystal grains on the sliding surface leads to improvement in the uniformity of an oil film formed on the sliding surface, which makes generation of scuffs less likely to occur even though an Al alloy base material has contact with the piston part. That is, contact between the Al alloy base material and the piston part is allowable. It is therefore possible to allow the Al alloy base material to have contact with the piston part while suppressing generation of scuffs. Configuring the cylinder body part such that Al is physically continuous from an Al contact portion where the Al alloy base material has contact with the piston part to a heat dissipation portion formed on an outer surface of the cylinder body part allows heat that the Al contact portion receives from the piston part to be efficiently transferred from the Al contact portion to the heat dissipation portion and emitted from the heat dissipation portion. As a result, the cooling efficiency of the air-cooled engine, and particularly the cooling efficiency at a time of initial sliding of the piston part, can be improved.

[0040] The present teaching is an teaching accomplished based on the above-described findings which are contradictory to the conventional design concept. To be specific, the present teaching allows the Al contact portion to have contact with the piston part while suppressing generation of scuffs, and thus achieves not only emission and transfer of heat from the heat dissipation portion but also efficient conduction and transfer of heat from the piston part through an inner peripheral surface (sliding surface) of the cylinder body part to an outer peripheral surface (heat dissipation portion) of the cylinder body part. Embodiments of the present teaching are described below with reference to the drawings.

<<First Embodiment>>

<Air-Cooled Engine>

[0041] Fig. 1 is a cross-sectional view schematically showing an air-cooled engine 150 according to a first embodiment of the present teaching. R represents the reciprocating direction of a piston part 122. U represents the upward direction, which means the direction away from a cylinder body part 100 and toward a cylinder head 130. L represents the downward direction, which means the direction away from the cylinder body part 100 and toward a crank case 110. The air-cooled engine 150 is of forced air-cooled type, and includes a cooling fan (not shown). The cooling fan is configured such that rotation of a crankshaft 111 is transmitted thereto. The air-cooled engine of the present teaching is not limited to the forced air-cooled type, but may be of natural air-cooled type. In the present teaching, no particular limitation is put on the number of cylinders of an air-cooled engine, though this

embodiment describes a single-cylinder engine. The air-cooled engine of this embodiment is a four-stroke engine, but instead it may be a two-stroke engine.

[0042] The air-cooled engine 150 includes the crank case 110, the cylinder body part 100, and the cylinder head 130. Although this embodiment illustrates the cylinder body part 100 and the crank case 110 configured as separate bodies, the cylinder body part 100 and the crank case 110 of the present teaching may be integrated as a single body.

[0043] The crank case 110 has the crankshaft 111 arranged therein. The crankshaft 111 includes a crank pin 112 and a crank web 113.

[0044] The cylinder body part 100 is provided above the crank case 110. The cylinder body part 100 includes a cylinder wall 103. The cylinder wall 103 is formed so as to define a cylinder bore 102. The cylinder wall 103 has, on its outer peripheral surface 103a, a heat dissipation portion 107 (fin). The heat dissipation portion 107 is a member with protrusions, which is provided in the outer peripheral surface 103a for the purpose of increasing the contact area with air. The heat dissipation portion 107 is not limited to the one having a plurality of plate-like portions as shown in Fig. 1. Examples of the heat dissipation portion include one having rod-like portions or acicular portions. The heat dissipation portion 107 may be formed in the outer peripheral surface 103a by shaping the outer peripheral surface 103a of the cylinder wall 103 into an accordion or wavelike form.

[0045] The piston part 122 is received in the cylinder bore 102 of the cylinder body part 100. The piston part 122 is configured to slide within the cylinder bore 102 while being in contact with a sliding surface 101 of the cylinder body part 100 (see Fig. 2). The piston part 122 is made of, for example, an Al alloy (typically, an Si-containing Al alloy). The piston part 122 is formed by, for example, forging as disclosed in the specification of United States Patent No. 6205836. The piston part 122 may be formed by casting.

[0046] No cylinder sleeve is provided in the cylinder bore 102. No plating is applied to an inner surface of the cylinder wall 103 of the cylinder body part 100. This embodiment, which requires no cylinder sleeve, can simplify a process for manufacturing the air-cooled engine 150, reduce the weight of the air-cooled engine 150, and improve cooling performance. In addition, since no plating need be applied to the inner surface of the cylinder wall 103, manufacturing costs can be reduced.

[0047] The cylinder head 130 is provided above the cylinder body part 100. The cylinder head 130, in combination with the piston part 122 of the cylinder body part 100, defines a combustion chamber 131. The cylinder head 130 includes an intake port 132 and an exhaust port 133. In the intake port 132, an intake valve 134 is arranged for supply of a mixed gas into the combustion chamber 131. In the exhaust port 133, an exhaust valve 135 is arranged for exhaust in the combustion chamber 131.

[0048] The piston part 122 and the crankshaft 111 are coupled to each other via a connecting rod 140. More specifically, a piston pin 123 of the piston part 122 is inserted through a through hole provided in a small-end portion 142 of the connecting rod 140, and a crank pin 112 of the crankshaft 111 is inserted through a through hole provided in a large-end portion 144 of the connecting rod 140, thereby coupling the piston part 122 to the crankshaft 111. Roller bearings (rolling-element bearings) 114 are provided between the crank pin 112 and an inner peripheral surface of the through hole of the large-end portion 144. Although the air-cooled engine 150 is not provided with an oil pump configured to forcibly feed a lubricant, the air-cooled engine of the present teaching may be provided with an oil pump.

[0049] Fig. 2 is a side view schematically showing the piston part 122 included in the air-cooled engine 150 shown in Fig. 1.

[0050] The cylinder wall 103 of the cylinder body part 100 has the sliding surface 101 formed on the inner peripheral side of the cylinder wall 103, and the outer peripheral surface 103a formed on the outer peripheral side of the cylinder wall 103, the outer peripheral surface 103a provided with the heat dissipation portion 107. The cylinder wall 103 and the heat dissipation portion 107 are integrally formed. The piston part 122 is arranged in the cylinder bore 102 defined by the cylinder wall 103. The piston part 122 includes a piston main body 122a and a piston ring part 122b. The piston main body 122a includes the piston pin 123 for insertion into the through hole of the connecting rod 140. The piston ring part 122b includes three (a plurality of) piston rings 122c, 122d, and 122e which are arranged on the outer periphery of the piston main body 122a.

[0051] The piston ring 122c, which is also referred to as a top ring, is fitted in a top ring groove 122f formed in the outer periphery of the piston main body 122a. The piston ring 122d, which is also referred to as a second ring, is fitted in a second ring groove 122g formed in the outer periphery of the piston main body 122a. The piston ring 122e, which is also referred to as an oil ring, is fitted in an oil ring groove 122h formed in the outer periphery of the piston main body 122a. The top ring 122c, the second ring 122d, and the oil ring 122e are arranged at intervals and in this sequence from top to down with respect to the reciprocating direction R of the piston part 122. In this embodiment, therefore, an upper end 122m of the piston ring part 122b with respect to the reciprocating direction R of the piston part 122 corresponds to an upper surface of the top ring 122c. A lower end 122n of the piston ring part 122b corresponds to a lower surface of the oil ring 122e. Of the piston part 122, in particular, the piston ring part 122b (the piston rings 122c, 122d, 122e) is in contact with the sliding surface 101 of the cylinder wall 103. Although this embodiment illustrates the piston ring part 122b including three piston rings, the number of piston rings included in the piston ring part 122b is not particularly limited.

[0052] The cylinder body part 100 is made of an Si-containing Al alloy. It more specifically is made of an Al alloy with an Si content of 16% by mass or more. Preferably, the Al alloy has an Al content of 73.4% by mass or more and 79.6% by mass or less, an Si content of 16% by mass or more and 24% by mass or less, and a copper content of 2.0% by mass or more and 5.0% by mass or less. The wear resistance and strength of the cylinder body part 100 can be increased. It is also preferable that the Si content is 18% by mass or more. It is also preferable that the Si content is 22% by mass or less. It is preferable that the Al alloy has a phosphorus content of 50 ppm by mass or more and 200 ppm by mass or less, and a calcium content of 0.01% by mass or less. The Al alloy having a phosphorus content of 50 ppm by mass or more and 200 ppm by mass or less can suppress coarsening of Si crystal grains, thus allowing the Si crystal grains to be uniformly dispersed in the alloy. In addition, the Al alloy having a calcium content of 0.01% by mass or less can ensure that an effect of refining the Si crystal grains be exerted by phosphorus, so that a metallographic structure with an excellent wear resistance is obtained.

[0053] The cylinder body part 100 includes the sliding surface 101 to have contact with the piston part 122 (see Fig. 1). The sliding surface 101 is a surface (an inner peripheral surface) of the cylinder wall 103 on the cylinder bore 102 side. In other words, the sliding surface 101 is the innermost surface of the inner peripheral surface of the cylinder wall 103 with respect to the radial direction of the cylinder body part 100. In the present teaching, contact of the sliding surface 101 with the piston part 122 includes contact of the sliding surface 101 with the piston part 122 with interposition of an oil film formed by the lubricant.

[0054] In this embodiment, below-described linear grooves 4 (see Fig. 3) are formed throughout the sliding surface 101. In the present teaching, no particular limitation is put on a region of the sliding surface 101 where the linear grooves 4 are formed. For example, the region of the sliding surface 101 where the linear grooves 4 are formed may be at least the upper quarter region of the sliding surface 101. For example, the region of the sliding surface 101 where the linear grooves 4 are formed may be at least the upper quarter region and the lower quarter region of the sliding surface 101. The upper quarter region of the sliding surface 101 means a region closest to the cylinder head among four regions obtained by equally dividing the entire sliding surface 101 into four with respect to the piston sliding direction (the central axis direction of the cylinder bore 102). The lower quarter region of the sliding surface 101 means a region closest to the crank case.

[0055] Fig. 3 is a plan view schematically showing, on an enlarged scale, the sliding surface 101 of the cylinder body part 100 according to the first embodiment. R represents the reciprocating direction of the piston part 122. Fig. 4 is a cross-sectional view schematically showing, on an enlarged scale, the sliding surface 101 of the cyl-

inder body part 100 according to the first embodiment. The cross-section shown in Fig. 4 is along the direction R. In Fig. 4, for illustrative convenience, only first linear grooves 4a of the linear grooves 4 are shown. In Fig. 4, the chain double-dashed line arrows are arrows indicative of a heat flow.

[0056] On the sliding surface 101, a plurality of Si primary crystal grains 1, a plurality of Si eutectic crystal grains 2, and an Al alloy base material 3 are exposed. Si crystal grains that are first deposited upon cooling of a molten Al-Si based alloy having a hypereutectic composition are called "Si primary crystal grains". Si crystal grains that are subsequently deposited are called "Si eutectic crystal grains". The Si primary crystal grain 1 is relatively large, and has a granular shape for example. The Si eutectic crystal grain 2 is relatively small, and has an acicular shape for example. Not all of the Si eutectic crystal grains 2 have acicular shape. Some of the Si eutectic crystal grains 2 may have granular shapes. In such a case, acicular Si eutectic crystal grains 2 among the plurality of Si eutectic crystal grains 2 serve as main crystal grains. The Al alloy base material 3 is a solid solution matrix containing Al. The cylinder body part 100 includes the plurality of Si primary crystal grains 1, the plurality of Si eutectic crystal grains 2, and the Al alloy base material 3. The plurality of Si primary crystal grains 1 and the plurality of Si eutectic crystal grains 2 are dispersed in the Al alloy base material 3.

[0057] The average crystal grain diameter of the Si primary crystal grains 1 is, for example, 8 μm or more and 50 μm or less. A sufficient number of Si primary crystal grains 1 exist per unit area of the sliding surface 101. Each of the Si primary crystal grains 1, therefore, receives a relatively low load during operation of the air-cooled engine 150. Breakdown of the Si primary crystal grains 1 during operation of the air-cooled engine 150 is suppressed. A portion of each Si primary crystal grain 1 embedded in the Al alloy base material 3 is large enough to make the Si primary crystal grain 1 less likely to fall off. This leads to reduction of wear of the sliding surface 101, which may be caused by fallen Si primary crystal grains 1. If the average crystal grain diameter of the Si primary crystal grains 1 is less than 8 μm , a portion of the Si primary crystal grain 1 embedded in the Al alloy base material 3 is small. The Si primary crystal grain 1 is therefore likely to fall off during operation of the air-cooled engine 150. Since fallen Si primary crystal grains 1 act as abrasive particles, much wear of the sliding surface 101 may occur. If the average crystal grain diameter of the Si primary crystal grains 1 is more than 50 μm , the number of Si primary crystal grains 1 existing per unit area of the sliding surface 101 is small. Each of the Si primary crystal grains 1, therefore, receives a high load during operation of the air-cooled engine 150, which may cause breakdown of the Si primary crystal grains 1. Since fragments of broken-down Si primary crystal grains 1 act as abrasive particles, much wear of the sliding surface 101 may occur. It is preferable that the average crystal

grain diameter of the Si primary crystal grains 1 is 12 μm or more.

[0058] In this embodiment, the cylinder body part 100 is made of an Al alloy with an Si content of 16% by mass or more and formed by a high-pressure die casting process (HPDC). The high-pressure die casting process is a casting process in which a pressure is applied to a molten so that the molten is supplied into a die under a pressure greater than atmospheric pressure. In the high-pressure die casting process, a portion to be the sliding surface 101 can be cooled at a high cooling speed (e.g., 4°C/sec or more and 50°C/sec or less). This makes it possible that, for example, the average crystal grain diameter of the Si primary crystal grains 1 is controlled to be 8 μm or more and 50 μm or less.

[0059] The average crystal grain diameter of the Si eutectic crystal grains 2 is less than the average crystal grain diameter of the Si primary crystal grains 1. Preferably, the average crystal grain diameter of the Si eutectic crystal grains 2 is 7.5 μm or less. The Si eutectic crystal grains 2 serve to reinforce the Al alloy base material 3. Refining the Si eutectic crystal grains 2 leads to improvement in the wear resistance and strength of the cylinder body part 100.

[0060] Here, a grain size distribution of the Si crystal grains in the cylinder body part 100 is described.

[0061] Fig. 5 is a graph showing a preferred example of the grain size distribution of the Si crystal grains.

[0062] In the graph of Fig. 5, an Si crystal grain having a crystal grain diameter of 1 μm to 7.5 μm is an Si eutectic crystal grain 2, and an Si crystal grain having a crystal grain diameter of 8 μm to 50 μm is an Si primary crystal grain 1. Preferably, the Si crystal grains 1, 2 of the cylinder body part 100 have a grain size distribution in which peaks appear where the crystal grain diameter is in a range of 1 μm to 7.5 μm and in a range of 8 μm to 50 μm . The wear resistance and strength of the cylinder body part 100 can be highly improved.

[0063] From the viewpoint of reinforcing the Al alloy base material 3 with the Si eutectic crystal grains 2, as shown in Fig. 5, it is preferable that the frequency at a first peak (a peak due to the Si eutectic crystal grains 2) in the crystal grain diameter range of 1 μm to 7.5 μm is five times greater than the frequency at a second peak (a peak due to the Si primary crystal grains 1) in the crystal grain diameter range of 8 μm to 50 μm .

[0064] As a way to control the average crystal grain diameters of the Si primary crystal grains 1 and the Si eutectic crystal grains 2, it is conceivable to adjust the speed of cooling a portion to be the sliding surface 101 in the step of forming a molded body by casting (below-described step S1c). In one specific example, casting is performed such that a portion to be the sliding surface 101 is cooled at a cooling speed of, for example, 4°C/sec or more and 50°C/sec or less, thus enabling the Si crystal grains 1 and 2 to be deposited with the Si primary crystal grains 1 having an average crystal grain diameter of 8 μm or more and 50 μm or less and the Si eutectic crystal

grains 2 having an average crystal grain diameter of 7.5 μm or less.

[0065] Next, the linear grooves 4 formed in the sliding surface 101 are described.

[0066] As shown in Figs. 3 and 4, a plurality of linear grooves 4 are formed in the sliding surface 101. In this embodiment, the plurality of linear grooves 4 include a plurality of first linear grooves 4a and a plurality of second linear grooves 4b. The plurality of first linear grooves 4a, which are shaped so as to extend from the upper left to the lower right in Fig. 3, are substantially in parallel with one another. The plurality of first linear grooves 4a form a striped pattern on the sliding surface 101. The plurality of second linear grooves 4b, which are shaped so as to extend from the upper right to the lower left in Fig. 3, are substantially in parallel with one another. The plurality of second linear grooves 4b form a striped pattern on the sliding surface 101. The plurality of first linear grooves 4a and the plurality of second linear grooves 4b are not in parallel but intersect with each other. Thus, the plurality of linear grooves 4 form a lattice pattern on the sliding surface 101.

[0067] At least two linear grooves 4 of the plurality of linear grooves 4 are substantially in parallel with each other. Some linear grooves 4 (the first linear grooves 4a) and the other linear grooves 4 (the second linear grooves 4b) of the plurality of linear grooves 4 may intersect with each other. It may also be acceptable that the plurality of linear grooves 4 are formed such that none of them intersect but all of them are substantially in parallel with one another. Here, being "substantially in parallel" means a state where adjacent linear grooves 4 extend without crossing each other. The meaning of being "substantially in parallel" can therefore be interpreted as follows. For example, even though adjacent linear grooves 4 are, in a strict sense, not in parallel with each other because of errors, misalignments, etc., caused during formation of the linear grooves 4; in the present teaching, the adjacent linear grooves 4 can be considered to be substantially in parallel with each other. Although a set of first linear grooves 4a and a set of second linear grooves 4b are provided as sets of parallel linear grooves in the sliding surface 101, the number of sets of parallel linear grooves is not particularly limited in the present teaching. Grooves belonging to different sets intersect with each other. A pattern formed by the plurality of linear grooves 4 provided in the sliding surface 101 is not limited to a square lattice pattern as shown in Fig. 3. A pattern formed by the plurality of linear grooves 4 may be a striped pattern as formed by the first linear grooves 4a or the second linear grooves 4b, or may be a polygonal lattice pattern such as a triangular lattice pattern. The square lattice pattern is an example of the polygonal lattice pattern. In the striped pattern and the lattice pattern, the pitch of grooves may not necessarily be constant.

[0068] In this embodiment, the plurality of linear grooves 4 form a regular pattern (a striped pattern, a polygonal lattice pattern, etc.). In this embodiment, the

Al alloy base material 3 as well as the Si primary crystal grains 1 included in the regular pattern is exposed on the sliding surface 101 such that it is contactable with the piston ring part 122b (the piston part 122). The sliding surface 101 having the linear grooves 4 formed therein in the regular pattern enables a lubricant to be dispersed with an improved uniformity, as compared with a conventional irregular sliding surface (a sliding surface on which Si crystal grains are exposed in the form of floating islands). As a consequence, in this embodiment, an oil film formed on the sliding surface 101 has a high uniformity. In the following, descriptions of the linear grooves 4 apply to both the first linear grooves 4a and the second linear grooves 4b, except where the first linear grooves 4a and the second linear grooves 4b are distinguished from each other.

[0069] As for the shapes of the linear grooves 4 in a plan view, the linear grooves 4 have straight-line shapes in a plan view, as shown in Fig. 3. In the present teaching, however, the shapes of the linear grooves 4 in a plan view are not limited to straight-line shapes, and it suffices that they are line-like shapes extending substantially in parallel with one another such that adjacent linear grooves 4 do not intersect. To be specific, it may be acceptable that the linear grooves 4 have curved-line shapes. The linear groove 4 may include a portion with a curved-line shape and a portion with a straight-line shape. The linear groove 4 may include a flexed portion. The plurality of linear grooves 4 may have different shapes in a plan view. All of the linear grooves 4 may have identical or substantially identical shapes in a plan view. It is not always necessary that each of the plurality of linear grooves 4 is formed continuous throughout the entire sliding surface 101. It is not always necessary that each of the plurality of linear grooves 4 extends to an end edge of the sliding surface 101. It may be acceptable that each of the plurality of linear grooves 4 includes a discontinuous portion on the sliding surface 101.

[0070] As for the width of the linear groove 4, no particular limitation is put on the width of the linear groove 4. Preferably, the width of the linear groove 4 is equal to or less than a maximum value of the grain diameter range of the Si primary crystal grains 1 in the grain size distribution in the cylinder body part 100. It is also preferable that the width of the linear groove 4 is about 10 μm or less. It is preferable that the width of the linear groove 4 is equal to or more than a minimum value of the grain diameter range of the Si eutectic crystal grains 2 in the grain size distribution in the cylinder body part 100. It is also preferable that the width of the linear groove 4 is about 5 μm or more. Although Fig. 5 illustrates the linear grooves 4 having a fixed width, this example does not limit the present teaching. It may be acceptable that the width of the linear groove 4 varies depending on its location. It may also be acceptable that the plurality of linear grooves 4 have different widths. It may also be acceptable that all of the linear grooves 4 have the same width or substantially the same width.

[0071] As for the depth of the linear groove 4, the linear groove 4 of this embodiment has a depth of 0.1 μm or more and less than 2.0 μm . In the present teaching, however, the depth of the linear groove 4 is not particularly limited. In the present teaching, in a case where the linear groove 4 has a depth of 0.1 μm or more and less than 2.0 μm , not only the linear groove 4 but also a groove having a depth (e.g., a depth of 2.0 μm or more) greater than the depth of the linear groove 4 may be formed in the sliding surface 101. In other words, in the present teaching, it may be acceptable that a groove (for example, a below-described linear groove 8) other than the linear groove defined in the present teaching is formed in the sliding surface. Here, the depth of the linear groove 4 may be 1.5 μm or less. The depth of the linear groove 4 may be 0.5 μm or more.

[0072] The linear groove 4 has such a cross-sectional shape that the width of the linear groove 4 decreases as the depth of the linear groove 4 increases. The cross-sectional shape of the linear groove 4 means the shape of a cross-section of the linear groove 4 in a plane perpendicular to the direction in which the linear groove 4 extends. In the present teaching, the cross-sectional shape of the linear groove 4 is not particularly limited. The cross-sectional shape of the linear groove 4 may be, for example, generally U-shaped or generally V-shaped as shown in Fig. 4. It is not necessary that all the cross-sections of the linear grooves 4 have identical shapes. Different portions of the linear groove 4 may have different cross-sectional shapes, or different linear grooves 4 may have different cross-sectional shapes. A portion (ridge) between linear grooves 4 may not necessarily have a flat surface as shown in Figs. 3 and 4. The portion between linear grooves 4 may have an inclined surface or may form a ridge line.

[0073] As for the pitch of the first linear grooves 4a, the plurality of first linear grooves 4a that are substantially in parallel are formed at such a pitch that a plurality of first linear grooves 4a exist between Si primary crystal grains 1. For example, as shown in Fig. 4, a plurality of first linear grooves 4a exist in a gap P between Si primary crystal grains 1. In addition, a portion of the sliding surface 101 existing between the plurality of first linear grooves 4a is exposed so as to be contactable with the piston part 122 (see Figs. 1 and 2). Since the portion of the sliding surface 101 contactable with the piston part 122 is adjacent to the first linear grooves 4a in a plan view, a lubricant can be smoothly supplied to the sliding surface 101. Preferably, the pitch of the first linear grooves 4a has a value within the range of the Si eutectic crystal grains 2 in the grain size distribution of the Si crystal grains in the cylinder body part 100. It is preferable that the pitch of the first linear grooves 4a is 5 μm or more. It is preferable that the pitch of the first linear grooves 4a is 10 μm or less. Although Fig. 3 illustrates a case where a pair of adjacent first linear grooves 4a extend at a constant pitch irrespective of location, this example does not limit the present teaching. The pitch of the pair of adjacent first

linear grooves 4a may not necessarily be constant. For example, it may be acceptable that each of adjacent first linear grooves 4a is formed in a meandering shape so that the pitch of the first linear grooves 4a varies depending on location. While the above descriptions are for the first linear grooves 4a, the same descriptions as those of the first linear grooves 4a apply to the second linear grooves 4b, and therefore descriptions of the second linear grooves 4b are omitted herein.

[0074] In this embodiment, at least one of the linear grooves 4 passes through an Si primary crystal grain 1 while breaking down the Si primary crystal grain 1. That is, at least one of the linear grooves 4 is formed so as to pass over an exposed surface of an Si primary crystal grain 1. This provides a further enhanced uniformity of dispersion of the lubricant on the sliding surface 101. The present teaching is not limited to this example.

[0075] In this embodiment, as shown in Fig. 4, the Si primary crystal grain 1 having the fracture surface 5a is exposed on the sliding surface 101. That is, in this embodiment, the Si primary crystal grain 1 exposed on the sliding surface 101 is at least partially broken down, and a surface (which means the fracture surface 5a) that appears on the Si primary crystal grain 1 as a result of the breakdown is exposed on the sliding surface 101. In this manner, an oil reservoir 5b is formed in the sliding surface 101. Since the fracture surface of the Si primary crystal grain 1 is textured, the oil reservoir 5b is capable of retaining a large amount of lubricant. The open area of the oil reservoir 5b is comparable with the cross-sectional area of the Si primary crystal grain 1 (the area of a portion exposed on the sliding surface 101). The depth of the oil reservoir 5b is less than the diameter of the Si primary crystal grain 1. Not only the plurality of first linear grooves 4a that are substantially in parallel with one another but also the oil reservoirs 5b including the fracture surfaces 5a of the Si primary crystal grains 1 are formed in the sliding surface 101. This enables an increased amount of lubricant to be retained while maintaining the uniformity of dispersion of the lubricant. Generation of scuffs can be suppressed more effectively. The fracture surfaces 5a are formed during a surface treatment performed on the cylinder body part 100, the surface treatment being performed after the cylinder body part 100 is formed by the casting process. More specifically, for example, the fracture surfaces 5a are formed while the Si primary crystal grains 1 are honed with a grinding stone.

[0076] Referring to Fig. 4, an Al contact portion 106 is a portion where the Al alloy base material 3 has contact with the piston ring part 122b (the piston part 122). An Si contact portion 108 is a portion where the Si primary crystal grain 1 has contact with the piston ring part 122b (the piston part 122).

[0077] The Al contact portion 106 is formed between the plurality of first linear grooves 4a. The Al contact portion 106 is exposed on the sliding surface 101 at a location between two adjacent Si primary crystal grains 1 (Si contact portions 108). The Al contact portion 106 constitutes

a part of the cylinder wall 103, and the cylinder wall 103 is formed integrally with the heat dissipation portion 107. That is, the Al contact portion 106 is formed integrally with the heat dissipation portion 107. The Al alloy base material 3, therefore, is physically continuous from the Al contact portion 106, which is contactable with the piston ring part 122b (the piston part 122), to the heat dissipation portion 107. Heat of the piston ring part 122b (the piston part 122) is partially transferred to the Al contact portion 106, reaches the heat dissipation portion 107 via the cylinder wall 103, and is emitted from the heat dissipation portion 107, as indicated by the chain double-dashed line arrows in Fig. 4. Accordingly, the cooling efficiency of the air-cooled engine 150, and particularly the cooling efficiency at a time of initial sliding of the piston ring part 122b (the piston part 122), is improved.

[0078] In this embodiment, as shown in Fig. 4, the plurality of linear grooves 4 (the first linear grooves 4a and the second linear grooves 4b) are formed at such a pitch that a plurality of linear grooves 4 exist between the Si primary crystal grains 1. Thus, a plurality of linear grooves 4 and a plurality of Al contact portions 106 exist between two adjacent Si contact portions 108. To be specific, a plurality of linear grooves 4 and a plurality of Al contact portions 106 alternately exist between two adjacent Si contact portions 108. This can improve the uniformity of dispersion of the lubricant. As a result, wear, etc., of the Al contact portion 106 can be suppressed effectively. It is therefore possible to allow the Al contact portion 106 to have contact with the piston ring part 122b (the piston part 122) while suppressing generation of scuffs.

[0079] The plurality of linear grooves 4 are formed at a pitch less than the average crystal grain diameter of the Si primary crystal grains 1. The plurality of linear grooves 4 are formed at a narrow pitch. The uniformity of dispersion of the lubricant can be further enhanced accordingly. This results in further improvement in the cooling efficiency of the air-cooled engine 150, and particularly the cooling efficiency at a time of initial sliding of the piston ring part 122b (the piston part 122).

<Manufacturing Process>

[0080] A process for manufacturing the cylinder body part 100 of this embodiment is described.

[0081] The cylinder body part 100 is manufactured by, for example, performing the following steps S1 to S4 in order:

- step S1 of preparing a molded body;
- step S2 of performing a fine boring;
- step S3 of performing a rough honing; and
- step S4 of performing a finishing honing.

[0082] In the process for manufacturing the cylinder body part 100, firstly, a molded body made of an Si-containing Al alloy is prepared (step S1). The molded body includes, near a surface thereof, Si primary crystal grains

and Si eutectic crystal grains. The step S1 of preparing the molded body includes, for example, steps S1a to S1e:

- step S1a of preparing a silicon-containing Al alloy;
- step S1b of producing a molten;
- step S1c of performing a high-pressure die casting process;
- step S1d of performing a heat treatment; and
- step S1e of performing a machining.

[0083] Firstly, an Si-containing Al alloy is prepared (step S1a). To ensure that the wear resistance and strength of the cylinder body part 100 be sufficiently high, it is preferable to adopt an Al alloy having an Al content of 73.4% by mass or more and 79.6% by mass or less, an Si content of 16% by mass or more and 24% by mass or less, and a copper content of 2.0% by mass or more and 5.0% by mass or less.

[0084] Then, the Al alloy thus prepared is heated and melted in a melting furnace, to form a molten (step S1b). It is preferable that about 100 ppm by mass of phosphorus is added to an unmelted Al alloy beforehand or to the molten. The Al alloy having a phosphorus content of 50 ppm by mass or more and 200 ppm by mass or less can suppress coarsening of Si crystal grains, thus allowing the Si crystal grains to be uniformly dispersed in the alloy. In addition, the Al alloy having a calcium content of 0.01% by mass or less can ensure that an effect of refining the Si crystal grains be exerted by phosphorus, so that a metallographic structure with an excellent wear resistance is obtained. For these reasons, it is preferable that the Al alloy has a phosphorus content of 50 ppm by mass or more and 200 ppm by mass or less and a calcium content of 0.01% by mass or less.

[0085] Then, a high-pressure die casting process is performed to cast the molten Al alloy (step S1c). To be specific, the molten is cooled in a casting mold, to form a molded body. At this time, a portion of the cylinder wall 103 to be the sliding surface 101 is cooled at a high cooling speed (e.g., 4°C/sec or more and 50°C/sec or less), so that a molded body including, near its surface, Si crystal grains which contribute to the wear resistance is obtained. For this casting step S1c, a casting apparatus disclosed in the WO2004/002658 pamphlet can be used, for example.

[0086] Then, the molded body removed from the casting mold is subjected to any of heat treatments called "T5", "T6", and "T7" (step S1d). T5 treatment is a treatment in which a molded body is quenched by water-cooling, etc. immediately after removed from a casting mold, then subjected to artificial aging at a predetermined temperature for a predetermined period for the purpose of improving mechanical properties and obtaining dimensional stabilization, and then air-cooled. T6 treatment is a treatment in which a molded body is subjected to a solution treatment at a predetermined temperature for a predetermined period after removed from a casting mold, then water-cooled, then subjected to an artificial aging

treatment at a predetermined temperature for a predetermined period, and then air-cooled. T7 treatment, which is a treatment in which overaging is made as compared with T6 treatment, is able to provide more dimensional stabilization than T6 treatment is, but can provide less hardness than T6 treatment can.

[0087] Subsequently, a predetermined machining process is performed on the molded body (step S1e). More specifically, a mating surface for mating with a cylinder head and a mating surface for mating with a crank case are ground, for example.

[0088] After the molded body is prepared in the above-described manner, a fine boring process is performed on a surface of the molded body, and more specifically on an inner peripheral surface (that is, a surface to be the sliding surface 101) of the cylinder wall 103, for the purpose of adjusting dimensional accuracy (step S2).

[0089] Then, the surface having the fine boring process performed thereon is subjected to a rough honing treatment (step S3). To be specific, the surface to be the sliding surface 101 is polished with a grinding stone of relatively low count (a grinding stone having large abrasive particles).

[0090] Then, a finishing honing treatment is performed (step S4). To be specific, of the surface of the molded body, a region to be the sliding surface 101 is polished with a grinding stone of relatively high count (a grinding stone having small abrasive particles). The rough honing treatment and the finishing honing treatment can be implemented by using, for example, a honing apparatus disclosed in Japanese Patent Application Laid-Open No. 2004-268179. Specifications (e.g., the type of the abrasive particles, the count (abrasive particle diameter), the type of a bonding agent, etc.) of the grinding stones used in the rough honing treatment and the finishing honing treatment can be set according to specifications of the linear grooves 4 to be formed in the sliding surface 101.

[0091] The sliding surface 101 of this embodiment is formed through the above-described steps. The plurality of Si primary crystal grains 1 and the Al alloy base material 3 are exposed on the sliding surface 101. While the piston part 122 is reciprocating in the cylinder bore 102, the plurality of Si primary crystal grains 1 and the Al alloy base material 3 have contact with the piston part 122. The sliding surface 101 has the plurality of linear grooves 4. The plurality of linear grooves 4 include the plurality of substantially parallel first linear grooves 4a and the plurality of substantially parallel second linear grooves 4b. In this embodiment, the linear grooves 4 are formed by using a grinding stone, but the present teaching is not limited to this example. The linear grooves 4 may be formed by using laser, for example. The number of times the rough honing treatment and the finishing honing treatment are performed is not limited to one, and they can be performed twice or more.

<<Second Embodiment>>

[0092] An air-cooled engine 150 according to a second embodiment is identical to the air-cooled engine 150 according to the first embodiment except that linear grooves 8 are formed instead of the linear grooves 4. In the following, therefore, a description of the linear grooves 8 is mainly given. The same features as those of the first embodiment are not described.

[0093] Fig. 6 is a plan view schematically showing, on an enlarged scale, a sliding surface 101 of a cylinder body part 100 according to the second embodiment. R represents the reciprocating direction of a piston part 122. Figs. 7(a) and 7(b) are cross-sectional views each schematically showing, on an enlarged scale, the sliding surface 101 of the cylinder body part 100 according to the second embodiment. The cross-sections shown in Figs. 7(a) and 7(b) are along the direction R. In Figs. 7(a) and 7(b), for illustrative convenience, only first linear grooves 8a of the linear grooves 8 are shown. In Fig. 7(a), the chain double-dashed line arrows are arrows indicative of a heat flow.

[0094] A plurality of linear grooves 8 are formed in the sliding surface 101. In this embodiment, the plurality of linear grooves 8 include a plurality of first linear grooves 8a and a plurality of second linear grooves 8b. The plurality of first linear grooves 8a, which are shaped so as to extend from the upper left to the lower right in Fig. 6, are substantially in parallel with one another. The plurality of first linear grooves 8a form a striped pattern on the sliding surface 101. The plurality of second linear grooves 8b, which are shaped so as to extend from the upper right to the lower left in Fig. 6, are substantially in parallel with one another. The plurality of second linear grooves 8b form a striped pattern on the sliding surface 101. The plurality of first linear grooves 8a and the plurality of second linear grooves 8b are not in parallel but intersect with each other. Thus, the plurality of linear grooves 8 form a lattice pattern on the sliding surface 101. In Fig. 6, portions where the Si primary crystal grains 1 and/or the Si eutectic crystal grains 2 overlap the linear grooves 8 indicate portions where the linear grooves 8 are formed so as to pass over exposed surfaces of the Si primary crystal grains 1 and/or the Si eutectic crystal grains 2. At least a part of these portions has a fracture surface 5a as shown in Fig. 7(b).

[0095] At least two linear grooves 8 of the plurality of linear grooves 8 are substantially in parallel with each other. Some linear grooves 8 (the first linear grooves 8a) and the other linear grooves 8 (the second linear grooves 8b) of the plurality of linear grooves 8 may intersect with each other. It may also be acceptable that the plurality of linear grooves 8 are formed such that none of them intersect but all of them are substantially in parallel with one another. Here, being "substantially in parallel" means a state where adjacent linear grooves 8 extend without crossing each other. The meaning of being "substantially in parallel" can therefore be interpreted as follows. For

example, even though adjacent linear grooves 8 are, in a strict sense, not in parallel with each other because of errors, misalignments, etc., caused during formation of the linear grooves 8; in the present teaching, the adjacent linear grooves 8 can be considered to be substantially in parallel with each other. Although a set of first linear grooves 8a and a set of second linear grooves 8b are provided as sets of parallel linear grooves in the sliding surface 101, the number of sets of parallel linear grooves is not particularly limited in the present teaching. Grooves belonging to different sets intersect with each other. A pattern formed by the plurality of linear grooves 8 provided in the sliding surface 101 is not limited to a square lattice pattern as shown in Fig. 5. A pattern formed by the plurality of linear grooves 8 may be a striped pattern as formed by the first linear grooves 8a or the second linear grooves 8b, or may be a polygonal lattice pattern such as a triangular lattice pattern. The square lattice pattern is an example of the polygonal lattice pattern. In the striped pattern and the lattice pattern, the pitch of grooves may not necessarily be constant.

[0096] In this embodiment, the plurality of linear grooves 8 form a regular pattern (a striped pattern, a polygonal lattice pattern, etc.). In this embodiment, the Al alloy base material 3 as well as the Si primary crystal grains 1 included in the regular pattern is exposed on the sliding surface 101 such that it is contactable with the piston ring part 122b (the piston part 122). The sliding surface 101 having the linear grooves 8 formed therein in the regular pattern enables a lubricant to be dispersed with an improved uniformity, as compared with a conventional irregular sliding surface (a sliding surface on which Si crystal grains are exposed in the form of floating islands). As a consequence, in this embodiment, an oil film formed on the sliding surface 101 has a high uniformity. In the following, descriptions of the linear grooves 8 apply to both the first linear grooves 8a and the second linear grooves 8b, except where the first linear grooves 8a and the second linear grooves 8b are distinguished from each other.

[0097] As for the shapes of the linear grooves 8 in a plan view, the linear grooves 8 have straight-line shapes in a plan view, as shown in Fig. 6. In the present teaching, however, the shapes of the linear grooves 8 in a plan view are not limited to straight-line shapes, and it suffices that they are line-like shapes extending substantially in parallel with one another such that adjacent linear grooves 8 do not intersect. To be specific, it may be acceptable that the linear grooves 8 have curved-line shapes. The linear groove 8 may include a portion with a curved-line shape and a portion with a straight-line shape. The linear groove 8 may include a flexed portion. The plurality of linear grooves 8 may have different shapes in a plan view. All of the linear grooves 8 may have identical or substantially identical shapes in a plan view. It is not always necessary that each of the plurality of linear grooves 8 is formed continuous throughout the entire sliding surface 101. It is not always necessary that

each of the plurality of linear grooves 8 extends to an end edge of the sliding surface 101. It may be acceptable that each of the plurality of linear grooves 8 includes a discontinuous portion on the sliding surface 101.

[0098] As for the width of the linear groove 8, no particular limitation is put on the width of the linear groove 8. Preferably, the width of the linear groove 8 is equal to or less than a maximum value of the grain diameter range of the Si primary crystal grains 1 in the grain size distribution in the cylinder body part 100. It is also preferable that the width of the linear groove 8 is about 10 μm or less. Preferably, the width of the linear groove 8 is equal to or more than a minimum value of the grain diameter range of the Si eutectic crystal grains 2 in the grain size distribution in the cylinder body part 100. It is also preferable that the width of the linear groove 8 is about 5 μm or more. Although Fig. 6 illustrates the linear grooves 8 having a fixed width, this example does not limit the present teaching. It may be acceptable that the width of the linear groove 8 varies depending on its location. It may also be acceptable that the plurality of linear grooves 8 have different widths. It may also be acceptable that all of the linear grooves 8 have the same width or substantially the same width.

[0099] As for the depth of the linear groove 8, the linear groove 8 of this embodiment has a depth equal to or more than one-third of the upper limit value of the grain diameter range of the Si eutectic crystal grains 2 in the grain size distribution of the Si crystal grains in the cylinder body part 100. Here, the significance of the depth of the linear groove 8 is described. Patent Literature 3 discloses a technique for suppressing generation of scuffs at or near the top dead center more effectively. In Patent Literature 3, a sliding surface is etched, and an Al alloy base material is removed in the depth direction substantially uniformly over the entire sliding surface except its regions having Si crystal grains which exist in the form of floating islands. In the technique of Patent Literature 3, therefore, it is preferable to perform the etching process so as to make the Si crystal grains less likely or unlikely to fall off from the sliding surface, which means that forming deep recesses or grooves is disadvantageous. In this embodiment, on the other hand, the linear grooves 8 are formed at a pitch greater than the average crystal grain diameter of the Si primary crystal grains, and thus a limited amount of the Al alloy base material is removed. It is therefore possible to form the linear grooves 8 having a relatively large depth. To be specific, the linear grooves 8 of this embodiment have a depth equal to or more than one-third of the upper limit value of the grain diameter range of the Si eutectic crystal grains 2 which generally have acicular shapes, but fall-off of the Si eutectic crystal grains 2 is prevented or suppressed. Since the average crystal grain diameter of the Si primary crystal grains 1 is larger than the average crystal grain diameter of the Si eutectic crystal grains 2, fall-off of the Si primary crystal grains 1 is also prevented or suppressed. Since the plurality of substantially parallel linear grooves with a rela-

tively large depth are formed in the sliding surface, a large amount of lubricant can be retained, so that the uniformity of dispersion of the lubricant is improved. Accordingly, this embodiment is able to prevent or suppress fall-off of the Si crystal grains with enhancement of the uniformity of the oil film. Preferably, the linear groove 8 has a depth of 2.0 μm or more. It may be acceptable that the linear groove 8 has a depth of 40% or more of the upper limit value of the grain diameter range of the Si eutectic crystal grains 2 in the grain size distribution of the Si crystal grains in the cylinder body part 100. It may also have a depth equal to or more than one-half of the upper limit value of the grain diameter range of the Si eutectic crystal grains 2 in the grain size distribution of the Si crystal grains in the cylinder body part 100.

[0100] Furthermore, it is preferable that the linear grooves 8 have a depth less than the upper limit value of the grain diameter range of the Si eutectic crystal grains 2. This allows the lubricant retained in the linear grooves 8 to be appropriately and efficiently supplied to the sliding surface 101. It is preferable that the linear grooves 8 have a depth of 6.0 μm or less. In the present teaching, in a case where the upper limit value and the lower limit value of the depth of the linear groove 8 are defined, a groove having a depth less than the lower limit value of the depth of the linear groove 8 and/or a groove having a depth more than the upper limit value of the depth of the linear groove 8 may be formed in the sliding surface 101. In other words, in the present teaching, it may be acceptable that a groove (for example, the above-described linear groove 8) other than the linear groove defined in the present teaching is formed in the sliding surface.

[0101] The linear groove 8 has such a cross-sectional shape that the width of the linear groove 8 decreases as the depth of the linear groove 8 increases. The cross-sectional shape of the linear groove 8 means the shape of a cross-section of the linear groove 8 in a plane perpendicular to the direction in which the linear groove 8 extends. In the present teaching, the cross-sectional shape of the linear groove 8 is not particularly limited. The cross-sectional shape of the linear groove 8 may be, for example, generally U-shaped or generally V-shaped as shown in Fig. 7(a). It is not necessary that all the cross-sections of the linear grooves 8 have identical shapes. Different portions of the linear groove 8 may have different cross-sectional shapes, or different linear grooves 8 may have different cross-sectional shapes. A portion (ridge) between linear grooves 8 may not necessarily have a flat surface as shown in Figs. 6, 7(a), and 7(b). The portion between linear grooves 8 may have an inclined surface or may form a ridge line. One or more grooves having a depth less than the depth of the linear groove 8 may be formed.

[0102] As for the pitch of the first linear grooves 8, the plurality of first linear grooves 8a that are substantially in parallel are formed at a pitch greater than the average crystal grain diameter of the Si primary crystal grains 1.

As a result, at least a part of the plurality of Si primary crystal grains 1 exists between adjacent first linear grooves 8a. In this embodiment, both the Si primary crystal grain 1 and the Al alloy base material 3 are exposed on the sliding surface 101 in a region between adjacent first linear grooves 8a such that both the Si primary crystal grain 1 and the Al alloy base material 3 are contactable with the piston part 122. Since the portion of the sliding surface 101 contactable with the piston part 122 is adjacent to the first linear grooves 8a in a plan view, a lubricant can be smoothly supplied to the sliding surface 101. Although the Al alloy base material 3 is exposed on the sliding surface 101 so as to be contactable with the piston part 122, the Si primary crystal grains 1 are also exposed on the sliding surface 101 so as to be contactable with the piston part 122, and therefore wear of the sliding surface 101 (the Al alloy base material 3) is suppressed more effectively. Although Fig. 6 illustrates a case where a pair of adjacent first linear grooves 8a extend at a constant pitch irrespective of location, this example does not limit the present teaching. The pitch of the pair of adjacent first linear grooves 8a may not necessarily be constant. For example, it may be acceptable that each of adjacent first linear grooves 8a is formed in a meandering shape so that the pitch of the first linear grooves 8a varies depending on location. While the above descriptions are for the first linear grooves 8a, the same descriptions as those of the first linear grooves 8a apply to the second linear grooves 8b, and therefore descriptions of the second linear grooves 8b are omitted herein.

[0103] In this embodiment, as shown in Fig. 6, at least one of the linear grooves 8 passes through an Si primary crystal grain 1 while breaking down the Si primary crystal grain 1. That is, at least one of the linear grooves 8 is formed so as to pass over an exposed surface of an Si primary crystal grain 1. This provides a further enhanced uniformity of dispersion of the lubricant on the sliding surface 101. The present teaching is not limited to this example.

[0104] In this embodiment, as shown in Fig. 7(b), the Si primary crystal grain 1 having the fracture surface 5a is exposed on the sliding surface 101. That is, in this embodiment, the Si primary crystal grain 1 exposed on the sliding surface 101 is at least partially broken down, and a surface (which means the fracture surface 5a) that appears on the Si primary crystal grain 1 as a result of the breakdown is exposed on the sliding surface 101. In this manner, an oil reservoir 5b is formed in the sliding surface 101. Since the fracture surface of the Si primary crystal grain 1 is textured, the oil reservoir 5b is capable of retaining a large amount of lubricant. The open area of the oil reservoir 5b is comparable with the cross-sectional area of the Si primary crystal grain 1 (the area of a portion exposed on the sliding surface 101). The depth of the oil reservoir 5b is less than the diameter of the Si primary crystal grain 1. Not only the plurality of first linear grooves 8a that are substantially in parallel with one another but also the oil reservoirs 5b including the fracture

surfaces 5a of the Si primary crystal grains 1 are formed in the sliding surface 101. This enables an increased amount of lubricant to be retained while maintaining the uniformity of dispersion of the lubricant. Generation of scuffs can be suppressed more effectively. The fracture surfaces 5a are formed during a surface treatment performed on the cylinder body part 100, the surface treatment being performed after the cylinder body part 100 is formed by the casting process. More specifically, for example, the fracture surfaces 5a are formed while the Si primary crystal grains 1 are honed with a grinding stone.

[0105] Referring to Fig. 7(a), an Al contact portion 106 is formed between the plurality of first linear grooves 8a. The Al contact portion 106 is exposed on the sliding surface 101 at a location between two adjacent Si primary crystal grains 1 (Si contact portions 108). The Al contact portion 106 constitutes a part of the cylinder wall 103, and the cylinder wall 103 is formed integrally with the heat dissipation portion 107. That is, the Al contact portion 106 is formed integrally with the heat dissipation portion 107. The Al alloy base material 3, therefore, is physically continuous from the Al contact portion 106, which is contactable with the piston ring part 122b (the piston part 122), to the heat dissipation portion 107. Heat of the piston ring part 122b (the piston part 122) is partially transferred to the Al contact portion 106, reaches the heat dissipation portion 107 via the cylinder wall 103, and is emitted from the heat dissipation portion 107, as indicated by the chain double-dashed line arrows in Fig. 7. Accordingly, the cooling efficiency of the air-cooled engine 150, and particularly the cooling efficiency at a time of initial sliding of the piston ring part 122b (the piston part 122), is improved.

[0106] In this embodiment, the plurality of linear grooves 8 (the first linear grooves 8a and the second linear grooves 8b) are formed at a pitch greater than the average crystal grain diameter of the Si primary crystal grains 1. As a result, one or more Si contact portions 108 exist between adjacent linear grooves 8. The linear grooves 8 (the first linear grooves 8a) have portions that extend between adjacent Si primary crystal grains 1. Thus, one or more Si contact portions 108 and one or more Al contact portions 106 exist between two adjacent linear grooves 8a. This can enhance the uniformity of an oil film formed on the sliding surface 101. In addition, a sufficient amount of lubricant can be retained in the linear grooves 8, because the plurality of linear grooves 8 have a depth equal to or more than one-third of the upper limit value of the grain diameter range of the Si eutectic crystal grains 2 in the grain size distribution of the Si crystal grains in the cylinder body part 100. Accordingly, discontinuity of the oil film on the sliding surface 101 can be suppressed. Furthermore, the plurality of linear grooves 8 have portions that extend between adjacent Si primary crystal grains 1. Since a load of the piston ring part 122b (the piston part 122) is received by the Si primary crystal grains 1, wear of the sliding surface 101 (the Al alloy base material 3) is suppressed in its regions near both sides

of the linear groove 8, so that the retention of the lubricant in the linear groove 8 is facilitated. In the air-cooled engine 150 of this embodiment, therefore, contact of the Al contact portion 106 with the piston ring part 122b (the piston part 122) is allowed with suppression of generation of scuffs. As a consequence, the cooling efficiency of the air-cooled engine 150, and particularly the cooling efficiency at a time of initial sliding of the piston part 122, is improved.

[0107] The plurality of linear grooves 8 have a depth that is equal to or more than one-third of the upper limit value of the grain diameter range of the Si eutectic crystal grains 2 in the grain size distribution of the Si crystal grains in the cylinder body part 100 and less than the upper limit value of the grain diameter range of the Si eutectic crystal grains 2 in the grain size distribution of the Si crystal grains in the cylinder body part 100. This ensures that a sufficient and appropriate amount of lubricant be retained in the plurality of linear grooves 8. The uniformity of the oil film is further improved. Thus, the cooling efficiency of the air-cooled engine 150, and particularly the cooling efficiency at a time of initial sliding of the piston part 122, can be still further improved.

[0108] The plurality of linear grooves 8 are formed at a pitch that is greater than the average crystal grain diameter of the Si primary crystal grains 1 and less than the distance from the lower end 122n of the piston ring part 122b to the upper end 122m of the piston ring part 122b with respect to the reciprocating direction of the piston part 122. This ensures that a sufficient and appropriate amount of lubricant be retained in the plurality of linear grooves 8. The uniformity of the oil film is improved. Thus, the cooling efficiency of the air-cooled engine 150, and particularly the cooling efficiency at a time of initial sliding of the piston part 122, can be still further improved.

[0109] While the above-described first and second embodiments illustrate the configuration in which the entire cylinder body part is made of an Al alloy with an Si content of 16% by weight or more, the present teaching is not limited to this example. In the present teaching, it suffices that the cylinder body part is made of an Al-containing metal and at least an inner peripheral portion of the cylinder body part is made of an Al alloy with an Si content of 16% by mass or more. In such a case, no particular limitation is put on the thickness of the inner peripheral portion of the cylinder body part with respect to the radial direction. The inner peripheral portion includes the sliding surface. In the present teaching, Al contained in the cylinder body part is physically continuous from the Al contact portion to the heat dissipation portion, which can improve the cooling properties of the air-cooled engine.

[0110] The present teaching can adopt the following configurations.

Of an cylinder body part, an inner peripheral portion including a sliding surface is made of an Al alloy with an Si content of 16% by mass or more. A portion other than the inner peripheral portion includes a heat dissipation portion, which is physically continuous with the inner pe-

ripheral portion. The portion other than the inner peripheral portion is made of an Al alloy having an Si content equal to or less than the Si content in the inner peripheral portion. An Al alloy base material contained in the cylinder body part is physically continuous from an Al contact portion to the heat dissipation portion.

[0111] This configuration, in which the Al alloy base material contained in the cylinder body part is physically continuous from the Al contact portion to the heat dissipation portion, provides an improvement in the cooling properties of the air-cooled engine.

[0112] The cylinder body part included in the air-cooled engine of the present teaching is not limited to the above-described example, and it may be configured, for example, as follows. The cylinder body part includes an outer cylindrical portion and a cylinder sleeve, the outer cylindrical portion provided on its outer surface with a heat dissipation portion, the cylinder sleeve being installed in the outer cylindrical portion. The cylinder sleeve of this configuration corresponds to the inner peripheral portion of the cylinder body part. The outer cylindrical portion corresponds to the portion of the cylinder body part other than the inner peripheral portion. No particular limitation is put on how the cylinder sleeve is installed, examples of which include fitting into the cylinder bore 102, casting around, or the like. The cylinder sleeve includes a sliding surface on which a piston part is slidable, and the sliding surface includes an Al contact portion where an Al alloy base material has contact with the piston part. The sliding surface is already described in the first or second embodiment, and therefore is not described below. The cylinder sleeve is made of an Al alloy with an Si content of 16% by mass or more. The cylinder sleeve has the composition described in the first embodiment, for example. The outer cylindrical portion may be made of an Al alloy with an Si content of 16% by mass or more, or may be made of an Al alloy or an Al material with an Si content of less than 16% by mass. The outer cylindrical portion may be made of an Al alloy with an Si content equal to the Si content in the cylinder sleeve, or may be made of an Al alloy or an Al material with an Si content less than the Si content in the cylinder sleeve. Since both the outer cylindrical portion and the cylinder sleeve are made of an Al-containing metal (an Si-containing Al alloy or an Si-containing Al material) and there is little or no difference between the thermal expansion coefficient of the outer cylindrical portion and the thermal expansion coefficient of the cylinder sleeve; separation of the outer cylindrical portion and the cylinder sleeve from each other, which can be caused by a temperature rise, is suppressed. That is, a state where the cylinder sleeve and the outer cylindrical portion are in direct physical contact with each other is maintained. Moreover, the Al alloy base material contained in an outer surface of the cylinder sleeve is in direct physical contact with the Al alloy base material or the Al material contained in an inner surface of the outer cylindrical portion. Thus, physical continuity of Al is ensured. The cylinder body part has Al physically

continuous from the Al contact portion to the heat dissipation portion. This means that, like the first and second embodiments, the cylinder body part has a heat transfer path made of Al that continuously extends from the Al contact portion to the heat dissipation portion. Such a cylinder body part including the outer cylindrical portion and the cylinder sleeve is one example of the cylinder body part of the present teaching.

10 <Cylinder Body Member>

[0113] The cylinder body member of this embodiment is itself the cylinder body part 100 of the first embodiment (see Fig. 1, etc.). The cylinder body part 100 is a part including the sliding surface 101. The cylinder body member of the present teaching, however, is not limited to this example. It suffices that the cylinder body member is provided with the cylinder body part 100 including the sliding surface 101. The cylinder body member of the present teaching may be a member (a so-called cylinder block) constituted of the cylinder body part 100 and the crank case 110 formed integrally with each other. Since the cylinder body member includes the heat dissipation portion 107 formed integrally with the Al contact portion 106 which is provided between the plurality of linear grooves 4 so as to be contactable with the piston part, application of the cylinder body to an air-cooled engine can enhance the cooling efficiency of the air-cooled engine. The cylinder body member of this embodiment may be the cylinder body part according to the second embodiment instead of the cylinder body part 100 according to the first embodiment. The cylinder body member of the present teaching may be itself the above-described cylinder body part including the outer cylindrical portion and the cylinder sleeve.

<Vehicle>

[0114] The vehicle of the present teaching includes various types of vehicles such as automobiles, motorcycles, snowcats as exemplified by snowmobiles, and the like. The number of wheels is not particularly limited to, for example, four, three, or two. The vehicle of the present teaching may be a box-type vehicle in which an engine is arranged in a place, such as an engine room, distant from a seat, or may be a straddled vehicle in which an engine is at least partially arranged below a seat straddled by a driver. The straddled vehicle includes a scooter-type vehicle that a driver can ride with feet together.

[0115] As an example of the vehicle, a motorcycle is illustrated below. Fig. 8 is a side view schematically showing a motorcycle including the air-cooled engine 150 according to the first embodiment.

[0116] In the motorcycle shown in Fig. 8, a head pipe 302 is arranged at the front end of a main body frame 301. A front fork 303 is attached to the head pipe 302, so as to be swingable in the lateral direction of the vehicle. A front wheel 304 is rotatably supported at the lower ends

of the front fork 303. A handlebar 305 is provided at the upper end of the front fork 303.

[0117] A rear frame 306 is provided so as to extend rearward from the upper side of a rear end portion of the main body frame 301. A fuel tank 307 is provided above the main body frame 301, and a main seat 308a and a tandem seat 308b are provided above the rear frame 306.

[0118] A rear arm 309 extending rearward is attached to the rear end portion of the main body frame 301. A rear wheel 310 is rotatably supported at the rear end of the rear arm 309.

[0119] The air-cooled engine 150 shown in Fig. 1 is held in a middle portion of the main body frame 301. The air-cooled engine 150 adopts the cylinder body part 100 of this embodiment. An exhaust tube 312 is connected to the exhaust port of the air-cooled engine 150. A muffler 313 is attached to the rear end of the exhaust tube 312.

[0120] The air-cooled engine 150 is coupled with a transmission 315. The transmission 315 has an output shaft 316 to which a drive sprocket 317 is attached. The drive sprocket 317 is coupled to a rear-wheel sprocket 319 of the rear wheel 310 via a chain 318. The transmission 315 and the chain 318 function as a transmission mechanism for transmitting power generated by the air-cooled engine 150 to a drive wheel.

[0121] The motorcycle (vehicle) of this embodiment, which is mounted with the air-cooled engine 150 including the cylinder body part 100 having the heat dissipation portion 107 formed integrally with the Al contact portion 106 that is provided between the plurality of linear grooves 4 so as to be contactable with the piston part 122, is able to enhance the cooling efficiency of the air-cooled engine. Although the motorcycle (vehicle) of this embodiment includes the air-cooled engine 150 according to the first embodiment, it may alternatively include the air-cooled engine 150 according to the second embodiment.

[0122] The average crystal grain diameters of the Si primary crystal grains and the Si eutectic crystal grains are measured by applying image processing to a portion of the cylinder body part to be the sliding surface. Based on the area of each Si crystal grain in an image obtained by the image processing, the diameter (equivalent diameter) of the Si crystal grain is calculated, assuming that the Si crystal grain in the image is in the shape of a true circle. A fine crystal having a diameter of less than 1 μm is not counted as the Si crystal grain (neither the Si primary crystal grain nor the Si eutectic crystal grain). In this manner, the number (frequency) and the diameters of the Si crystal grains are identified. Based on them, a grain size distribution of the Si crystal grains in the cylinder body part is obtained. The grain size distribution is, for example, a histogram as shown in Fig. 5. The grain size distribution has two peaks. The grain size distribution is divided into two regions, the threshold for the division being the diameter value corresponding to a valley portion between the two peaks. A region corresponding to a larger diameter is defined as a grain size distribution

of the Si primary crystal grains. A region corresponding to a smaller diameter is defined as a grain size distribution of the Si eutectic crystal grains. The average crystal grain diameter of the Si primary crystal grains and the average crystal grain diameter of the Si eutectic crystal grains are calculated based on the grain size distributions, respectively.

[0123] The width of the linear groove is the distance between a pair of adjacent ridge lines in a cross-section (profile curve) across the linear groove. The cross-section is in parallel with the direction in which the piston part slides relative to the sliding surface (the reciprocating direction R of the piston part). The cross-section is also in parallel with the radial direction of the cylinder body part. The depth of the linear groove is the depth from the higher one of a pair of ridge lines that are adjacent to a linear groove to the lowest point of the linear groove. The pitch of the linear grooves is the distance between the lowest points of a pair of adjacent grooves in the cross-section (profile curve). In a configuration in which portions of the sliding surface adjacent to a linear groove have substantially flat surfaces, the width of the linear groove is the distance between edges of a pair of such portions (flat surfaces) of the sliding surface.

[0124] In the present teaching, for the width, depth, and pitch of the linear grooves, respective values averaged over linear grooves included in a profile curve within 3 to 5 mm are adopted. In the present teaching, a groove other than the linear groove having the depth specified in the present teaching may be formed in the sliding surface. In such a case, the linear grooves having the depth specified in the present teaching are used to identify the width and pitch of the linear grooves.

[0125] It should be understood that the terms and expressions used herein are for descriptions and not to be construed in a limited manner, do not eliminate any equivalents of features shown and mentioned herein, and allow various modifications falling within the claimed scope of the present teaching.

[0126] The present teaching may be embodied in many different forms. The present disclosure is to be considered as providing examples of the principles of the teaching. A number of illustrative embodiments are described herein with the understanding that such examples are not intended to limit the teaching to preferred embodiments described herein and/or illustrated herein.

[0127] While some illustrative embodiments of the teaching have been described herein, the present teaching is not limited to the various preferred embodiments described herein. The present teaching includes any and all embodiments having equivalent elements, modifications, omissions, combinations (e.g., of aspects across various embodiments), adaptations and/or alterations as would be appreciated by those in the art based on the present disclosure. The limitations in the claims are to be interpreted broadly based on the language employed in the claims and not limited to examples described in the present specification or during the prosecution of the

application, which examples are to be construed as non-exclusive. For example, in the present disclosure, the term "preferably" is non-exclusive and means "preferably, but not limited to".

Reference Signs List

[0128]

1	Si primary crystal grain
2	Si eutectic crystal grain
3	Al alloy base material
4	linear groove
4a	first linear groove
4b	second linear groove
5a	fracture surface
5b	oil reservoir
100	cylinder body part (cylinder body member)
101	sliding surface
102	cylinder bore
103	cylinder wall
106	Al contact portion
107	heat dissipation portion
122	piston part
122a	piston main body
122b	piston ring part
122c	top ring (piston ring)
122d	second ring (piston ring)
122e	oil ring (piston ring)
122f	top ring groove
122g	second ring groove
122h	oil ring groove
122m	upper end (of piston ring part 122b)
122n	lower end (of piston ring part 122b)
123	piston pin
140	connecting rod
150	air-cooled engine

Claims

1. An air-cooled engine comprising a piston part and a cylinder body part with a sliding surface on which the piston part is slidable,
the cylinder body part including a heat dissipation portion provided on an outer surface of the cylinder body part, the cylinder body part being made of an Al-containing metal, at least an inner peripheral portion of the cylinder body part being made of an Al alloy with an Si content of 16% by mass or more, the inner peripheral portion including the sliding surface, the sliding surface being configured such that a plurality of substantially parallel linear grooves are formed therein and Si primary crystal grains are exposed thereon so as to be contactable with the piston part, the Si primary crystal grains having an average crystal grain diameter of 8 μm or more and 50 μm or less,

the sliding surface having an Al contact portion exposed thereon at a location between two adjacent Si primary crystal grains, the Al contact portion being formed between the plurality of linear grooves, the Al contact portion being a portion where an Al alloy base material has contact with the piston part, Al in the cylinder body part being physically continuous from the Al contact portion to the heat dissipation portion.

2. An air-cooled engine comprising a piston part and a cylinder body part with a sliding surface on which the piston part is slidable,
the cylinder body part including a heat dissipation portion provided on an outer surface of the cylinder body part, the cylinder body part being made of an Al-containing metal, at least an inner peripheral portion of the cylinder body part being made of an Al alloy with an Si content of 16% by mass or more and formed by a high-pressure die casting process, the inner peripheral portion including the sliding surface, the sliding surface being configured such that a plurality of substantially parallel linear grooves are formed therein and Si primary crystal grains are exposed thereon so as to be contactable with the piston part,
the sliding surface having an Al contact portion exposed thereon at a location between two adjacent Si primary crystal grains, the Al contact portion being formed between the plurality of linear grooves, the Al contact portion being a portion where an Al alloy base material has contact with the piston part, Al in the cylinder body part being physically continuous from the Al contact portion to the heat dissipation portion.
3. The air-cooled engine according to claim 1 or 2, wherein
a portion of the cylinder body part other than the inner peripheral portion is provided with the heat dissipation portion, physically continuous with the inner peripheral portion, and made of an Al alloy having an Si content equal to or less than the Si content in the inner peripheral portion, and
the Al alloy base material included in the cylinder body part is physically continuous from the Al contact portion to the heat dissipation portion.
4. The air-cooled engine according to any one of claims 1 to 3, wherein
the Al contact portion is exposed on the sliding surface at a location between two adjacent Si primary crystal grains, and the Al contact portion is formed integrally with the heat dissipation portion.
5. The air-cooled engine according to any one of claims 1 to 4, wherein
the plurality of linear grooves are formed at such a

pitch that a plurality of linear grooves exist between the Si primary crystal grains.

6. The air-cooled engine according to claim 5, wherein the pitch is less than the average crystal grain diameter of the Si primary crystal grains. 5

7. The air-cooled engine according to any one of claims 1 to 4, wherein 10
the cylinder body part includes Si eutectic crystal grains in addition to the Si primary crystal grains and the Al alloy base material, the Si eutectic crystal grains having an average crystal grain diameter less than the average crystal grain diameter of the Si primary crystal grains, and 15
the plurality of linear grooves have a depth equal to or more than one-third of an upper limit value of a diameter range of the Si eutectic crystal grains in a grain size distribution of Si crystal grains in the cylinder body part, the plurality of linear grooves being 20
formed at a pitch greater than the average crystal grain diameter of the Si primary crystal grains at least in an upper quarter region of the sliding surface, the plurality of linear grooves having a portion that exists 25
between adjacent ones of the Si primary crystal grains.

8. The air-cooled engine according to claim 7, wherein the plurality of linear grooves have a depth equal to or more than one-third of an upper limit value of a diameter range of the Si eutectic crystal grains and less than the upper limit value of the diameter range of the Si eutectic crystal grains, in a grain size distribution of Si crystal grains in the cylinder body part. 30
35

9. The air-cooled engine according to claim 7 or 8, wherein 40
the piston part comprises a piston main body and a piston ring part, the piston ring part including a plurality of piston rings arranged on an outer periphery of the piston main body, and
the plurality of linear grooves are formed at a pitch that is greater than the average crystal grain diameter of the Si primary crystal grains and less than the distance from a lower end of the piston ring part to an upper end of the piston ring part with respect to a reciprocating direction of the piston part. 45

10. The air-cooled engine according to any one of claims 1 to 9, wherein 50
the Si primary crystal grains exposed on the sliding surface are at least partially broken down, and a surface appearing on the Si primary crystal grain as a result of the breakdown is exposed on the sliding surface. 55

11. A cylinder body member comprising the cylinder body part included in the air-cooled engine according

to any one of claims 1 to 10.

12. A vehicle comprising the air-cooled engine according to any one of claims 1 to 10.

FIG.1

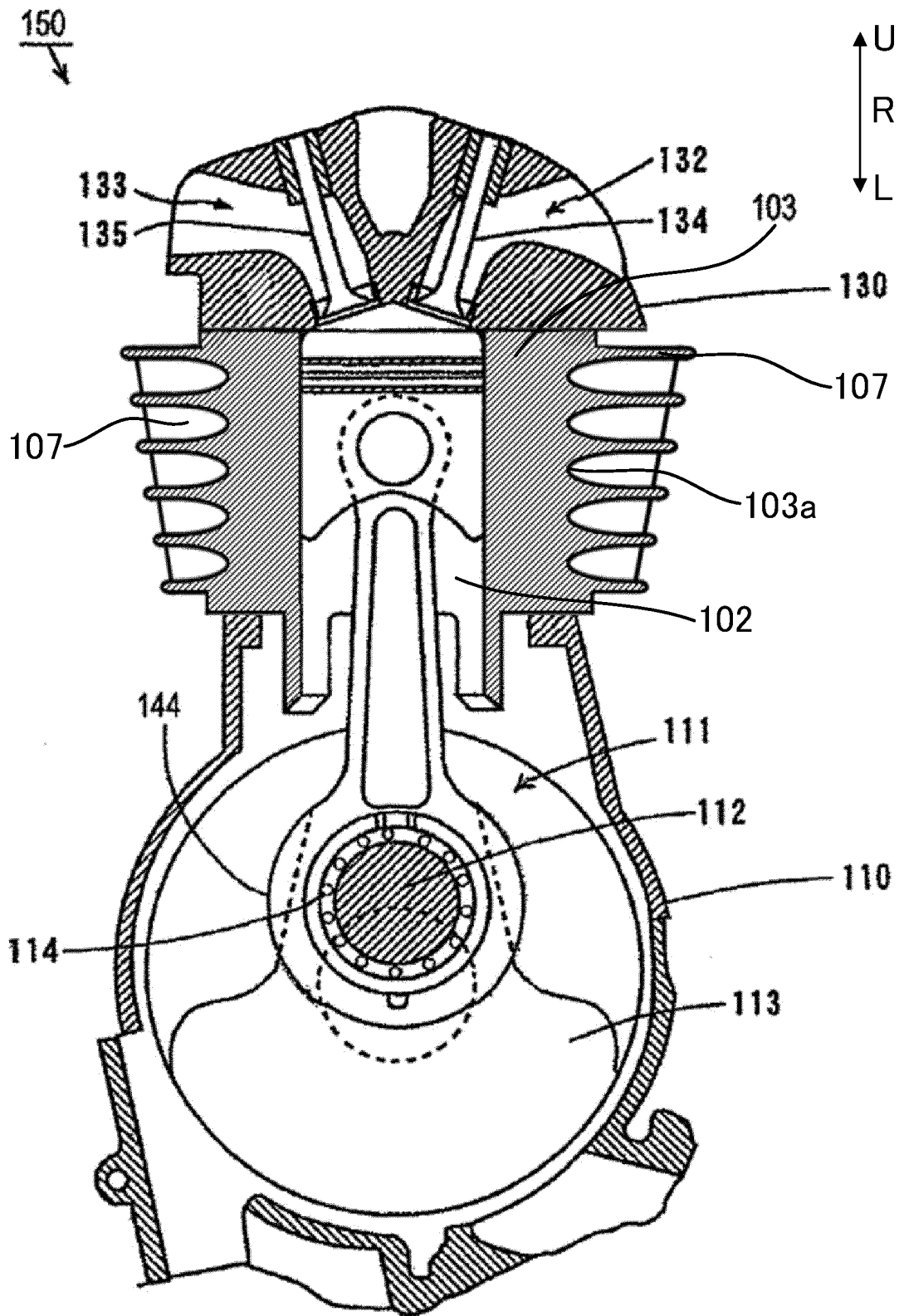


FIG.2

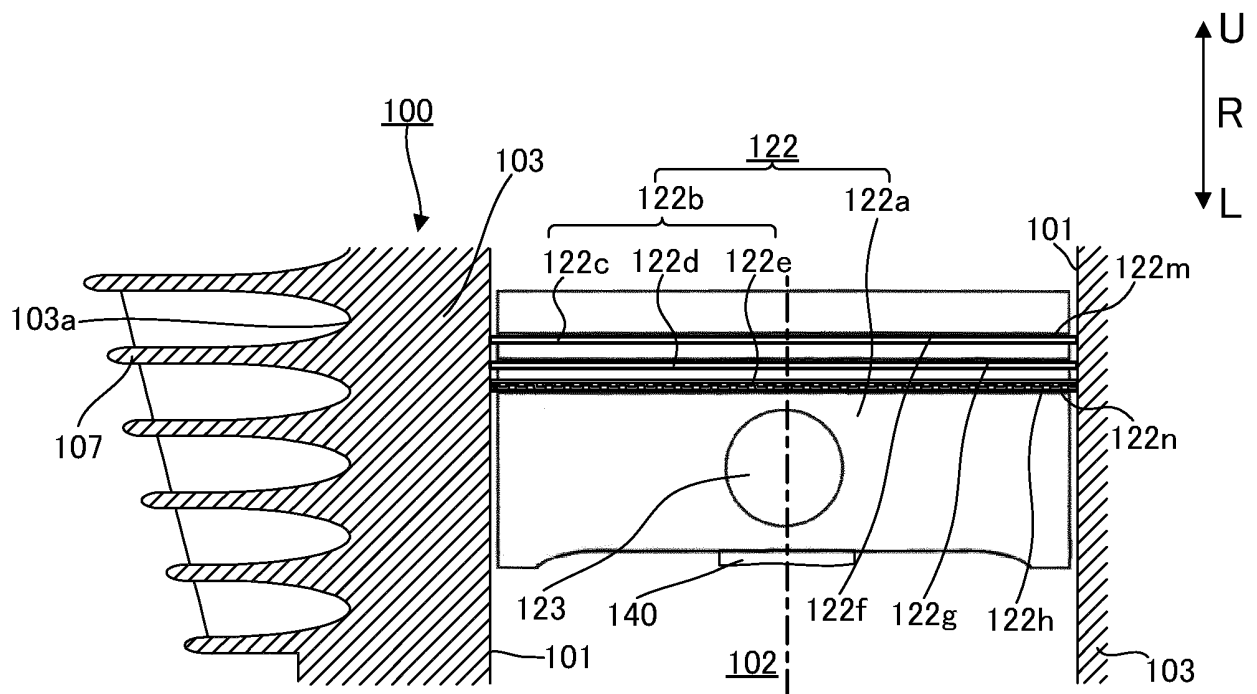


FIG.3

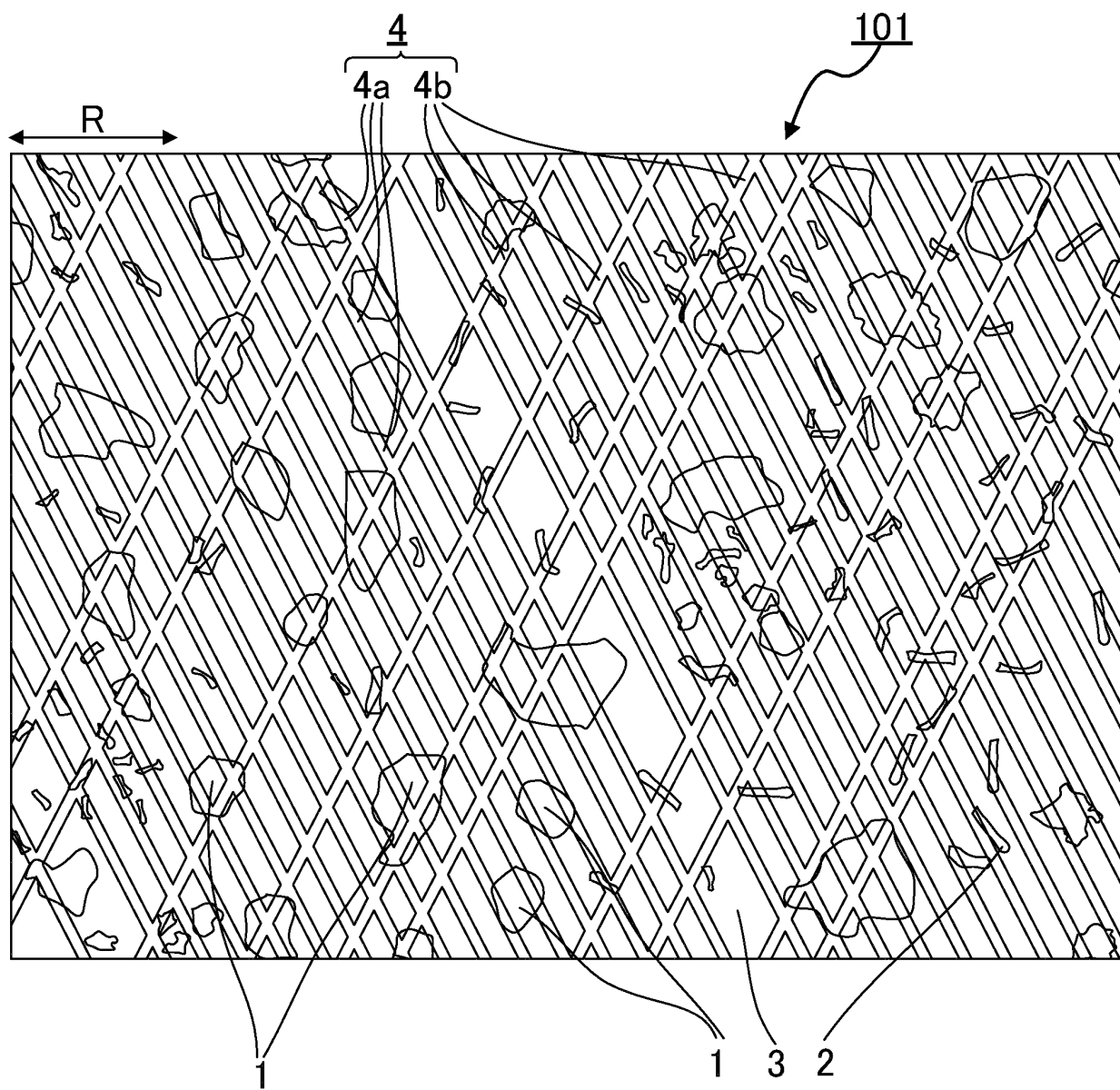


FIG.4

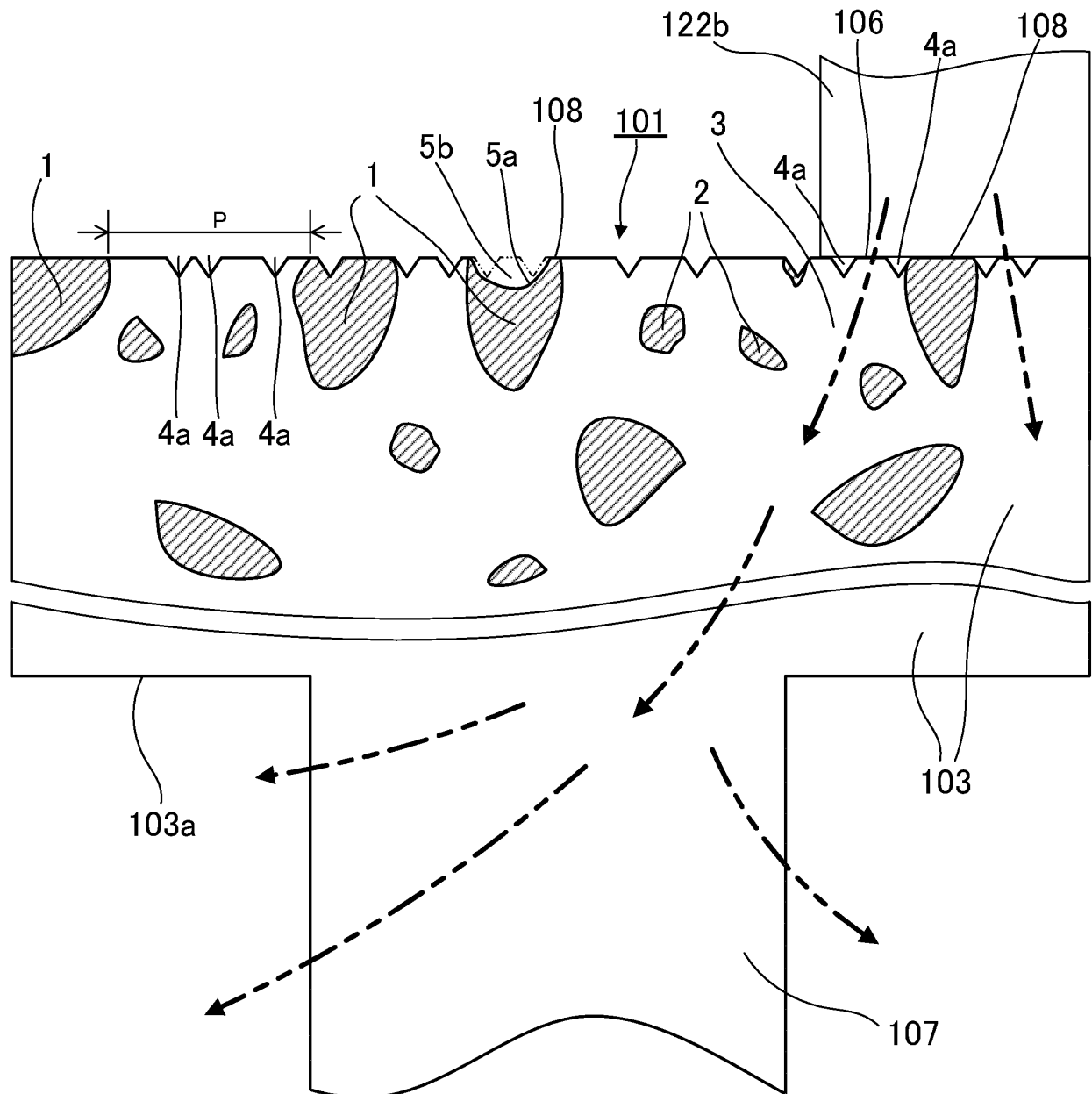


FIG.5

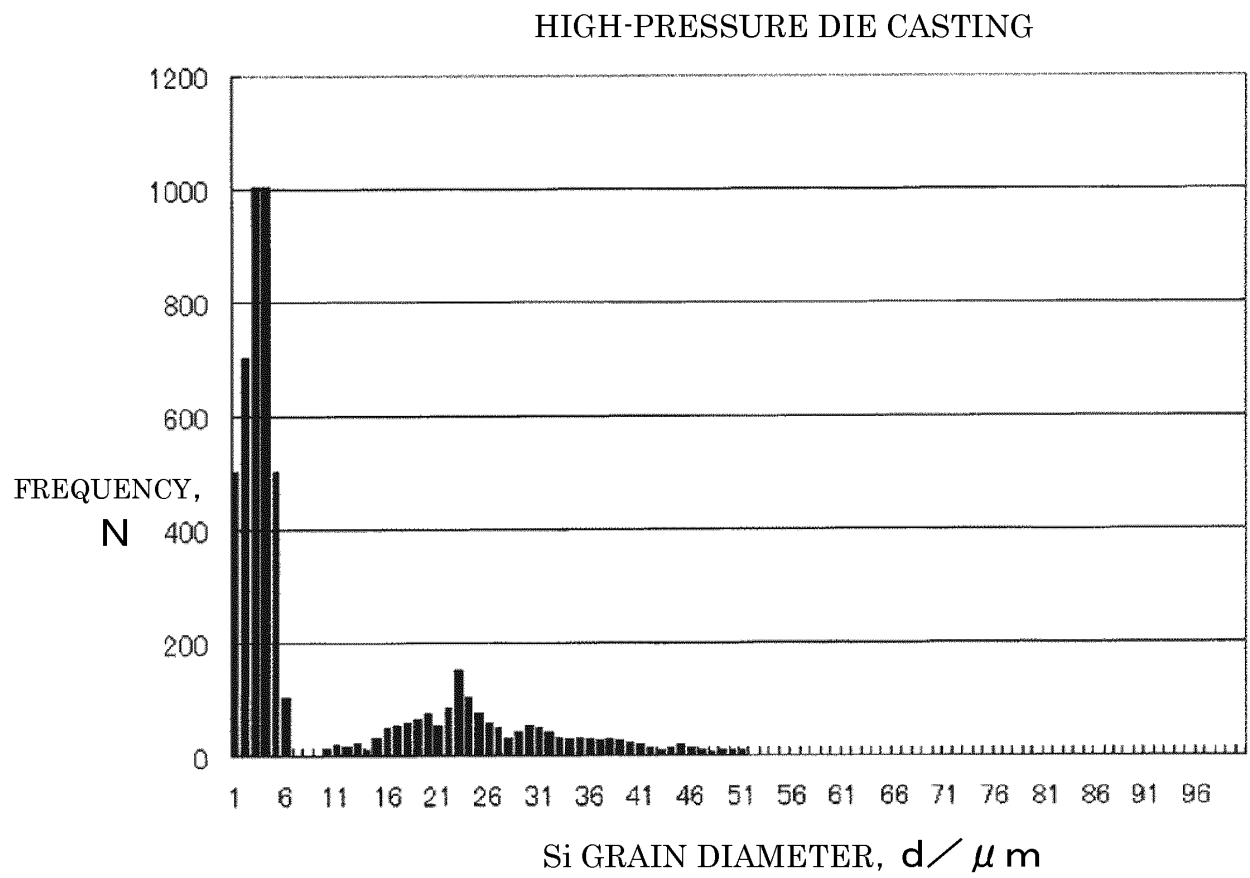


FIG.6

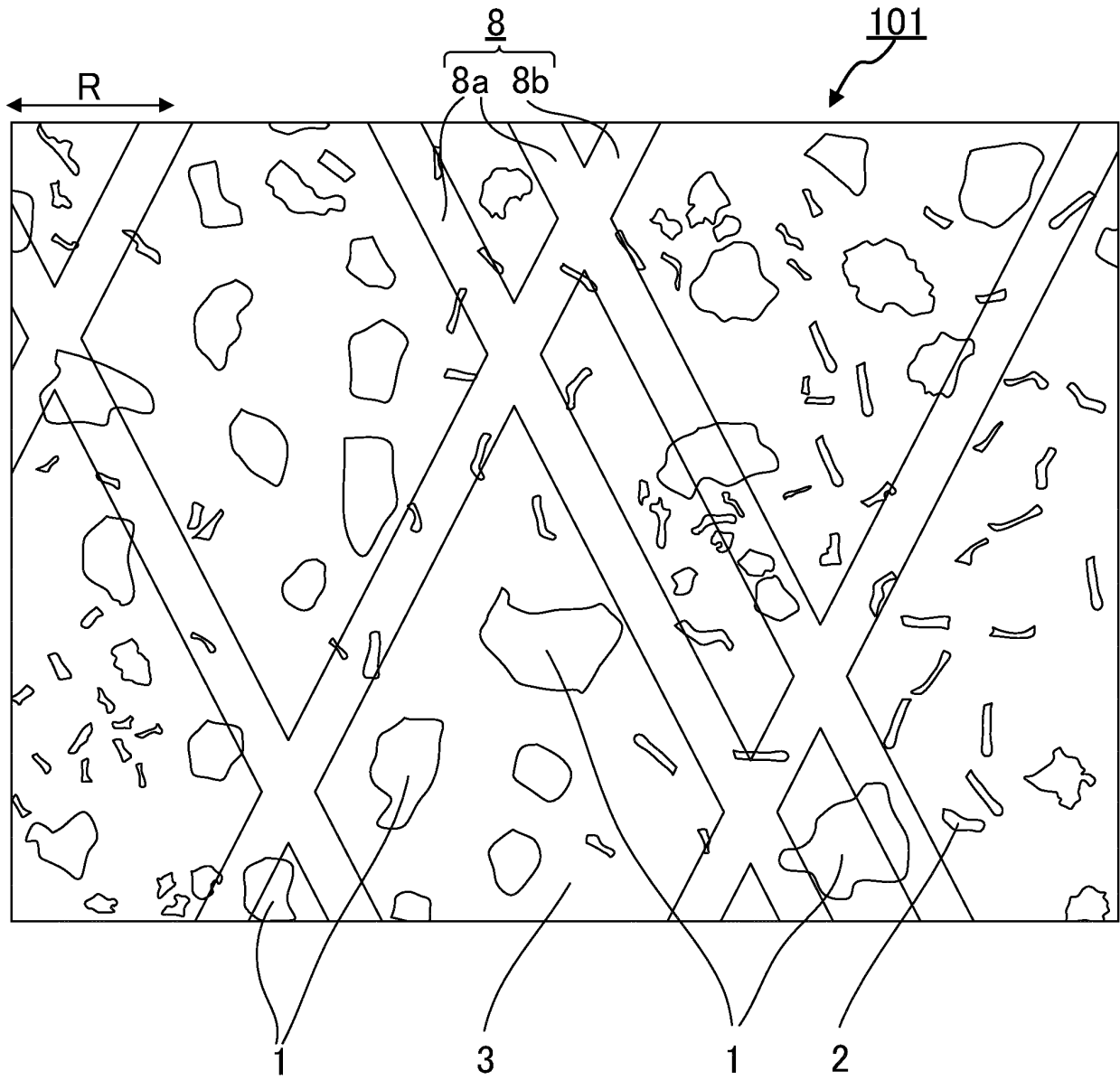


FIG. 7

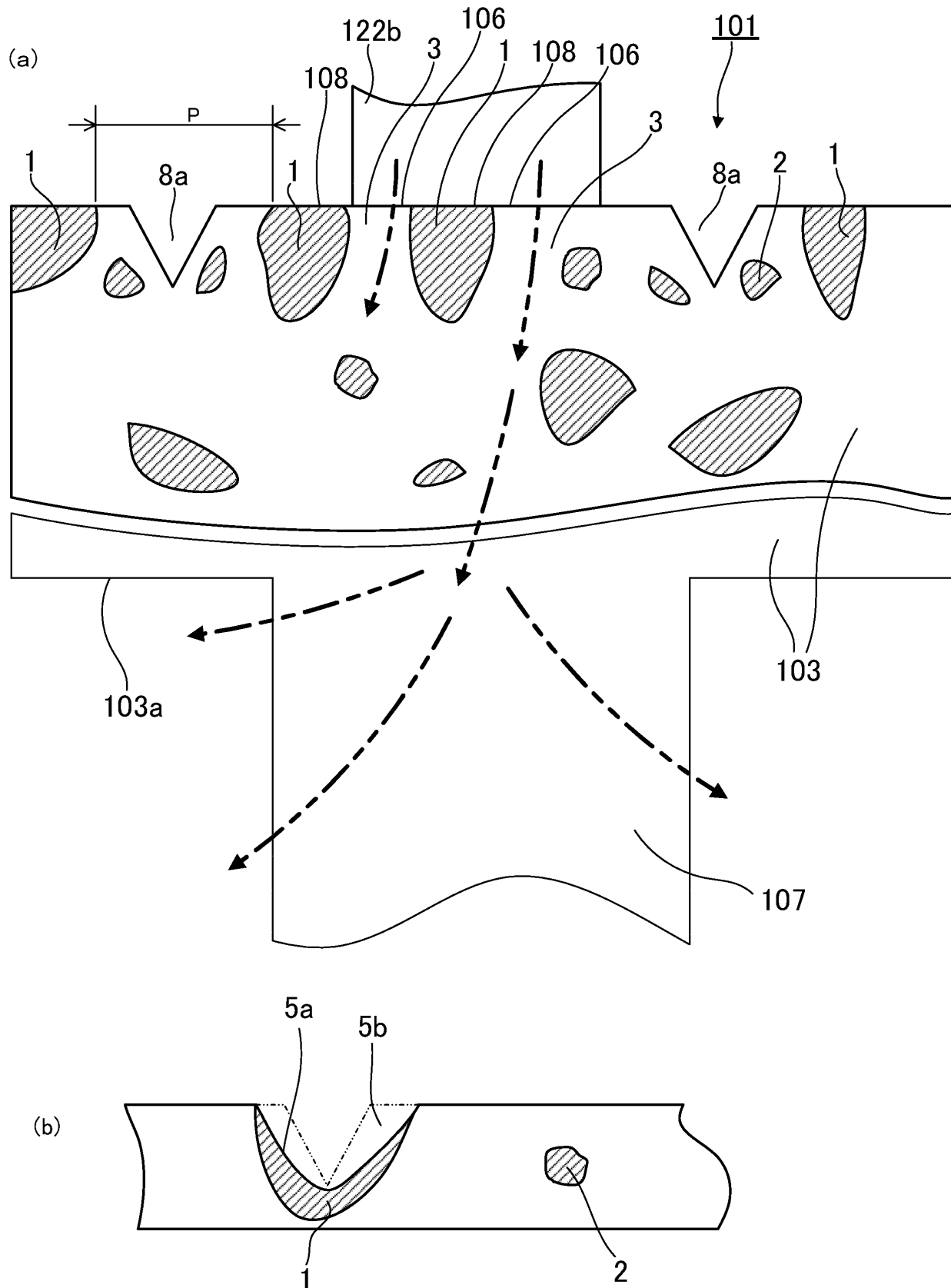
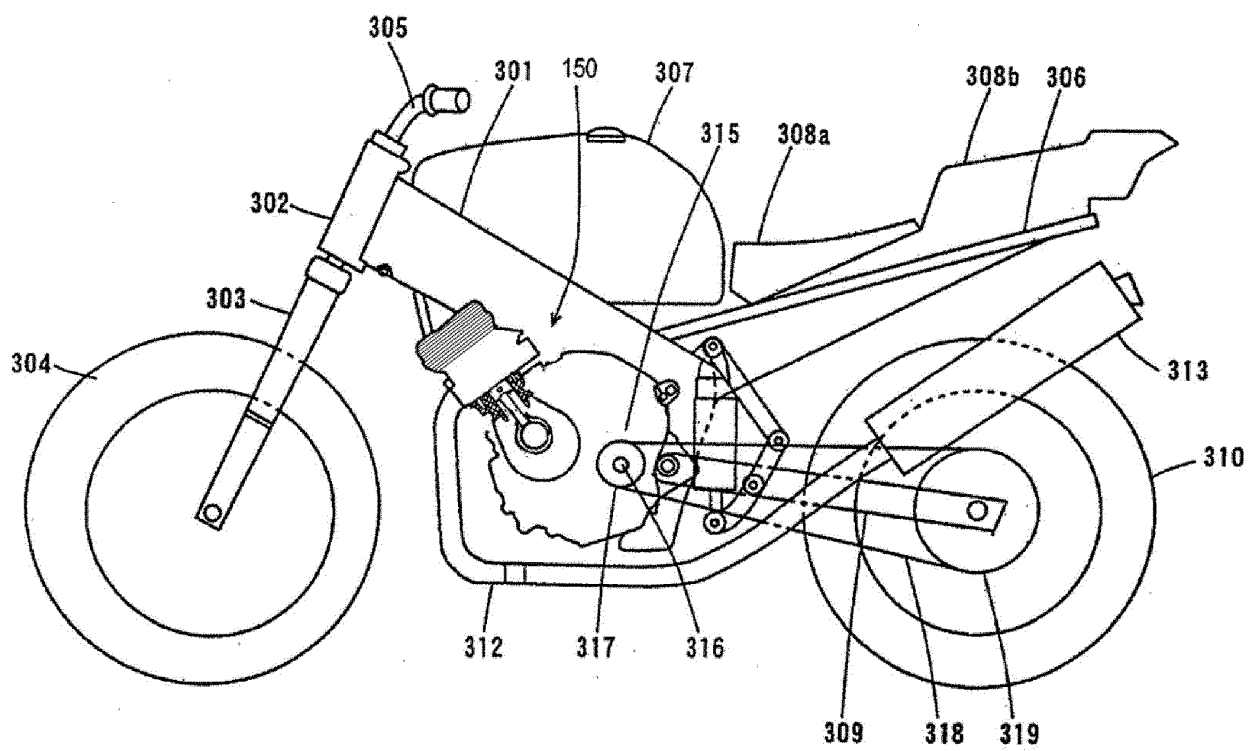


FIG.8



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/081066

A. CLASSIFICATION OF SUBJECT MATTER

F02F1/06(2006.01)i, F02F1/00(2006.01)i, F02F1/20(2006.01)i, F01P1/02(2006.01)i, C22C21/02(2006.01)i, C22F1/00(2006.01)n, C22F1/043(2006.01)n

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F02F1/00-1/42, F01P1/02, C22C21/00-21/18, C22F1/00-1/057, F16J10/00-10/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2015

Kokai Jitsuyo Shinan Koho 1971-2015 Toroku Jitsuyo Shinan Koho 1994-2015

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2010-274386 A (Toyota Central Research and Development Laboratories, Inc.), 09 December 2010 (09.12.2010), fig. 1 to 2, 4 (Family: none)	1-12
A	JP 2002-221077 A (Nissan Motor Co., Ltd.), 09 August 2002 (09.08.2002), fig. 1, 7 (Family: none)	1-12
A	JP 4-189465 A (Nissan Motor Co., Ltd.), 07 July 1992 (07.07.1992), fig. 1, 4, 6 (Family: none)	1-12

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search
25 November 2015 (25.11.15)

Date of mailing of the international search report
08 December 2015 (08.12.15)

Name and mailing address of the ISA/
Japan Patent Office
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Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/081066

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 8-246087 A (Mercedes-Benz AG.), 24 September 1996 (24.09.1996), fig. 2 & US 6096143 A fig. 2 to 2a & GB 2294471 A & DE 4438550 A1 & FR 2726212 A1 & CN 1129743 A & KR 1996-0014729 A	1-12
A	JP 8-260960 A (Suzuki Motor Corp.), 08 October 1996 (08.10.1996), fig. 1 to 5 & CN 1135569 A & KR 1996-0034676 A & MY 123041 A	1-12
A	JP 10-54296 A (Suzuki Motor Corp.), 24 February 1998 (24.02.1998), fig. 1 to 12 (Family: none)	1-12
A	JP 11-101112 A (Fuji Heavy Industries Ltd.), 13 April 1999 (13.04.1999), fig. 1 to 3 (Family: none)	1-12

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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- JP 8260960 A [0005]
- JP 10054296 A [0005]
- JP 11101112 A [0005]
- US 6205836 B [0045]
- WO 2004002658 A [0085]
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