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(54) **INTERNAL COMBUSTION ENGINE MANUFACTURING METHOD, INTERNAL COMBUSTION ENGINE, AND COUPLING CYLINDER**

(57) To achieve excellent maintainability and recycling efficiency for an internal combustion engine and a high degree of freedom in design of the internal combustion engine, provided are a method of manufacturing an internal combustion engine, an internal combustion engine manufactured by using the method, and a connected cylinder to be used therefor . The method of manufacturing an internal combustion engine (100) includes at least a fitting step of fitting a connected cylinder (10) to a hollow portion (64) of a cylinder block main body (60), the connected cylinder (10) including any one of connected cylinders selected from the group consisting of: (1) a first connected cylinder including two or more cylinder liners and a connecting portion configured to connect the two or more cylinder liners to each other; and (2) a second connected cylinder including a connected cylinder main body portion having two or more cylinder bores and a coating configured to cover an inner peripheral surface of the connected cylinder main body portion in which the cylinder bores are formed, the cylinder block main body (60) having one end side where a crankcase (62) is formed and another end side where a cylinder head is attachable, the hollowportion (64) passing through the cylinder block main body (60) from the one end side to the another end side.

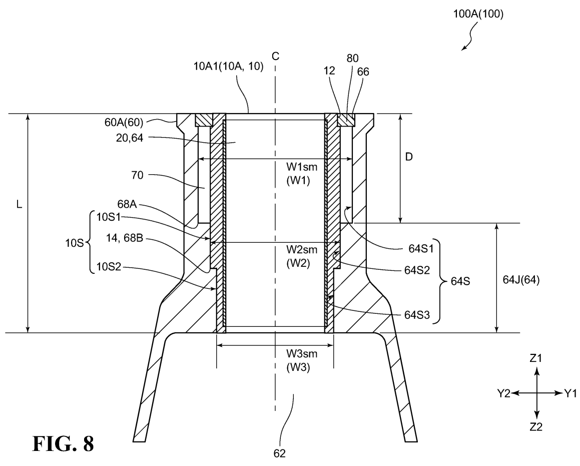

FIG. 8

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Description

Technical Field

[0001] The present invention relates to a method of manufacturing an internal combustion engine, to an internal combustion engine, and to a connected cylinder.

Background Art

[0002] Hitherto, as a cylinder block used for purpose of, for example, reduction in size and weight of a reciprocating-type multi-cylinder internal combustion engine, there has been known a so-called Siamese-type cylinder block having a structure formed by integrally connecting cylinder liners which respectively form adjacent cylinder bores . As a method of manufacturing the cylinder block described above, there have been known, for example, (1) a method of placing a group of cylinder liners in a die at the time of casting of the cylinder block and then casting the group of cylinder liners into a cylinder block main body to fix the group of cylinder liners to the cylinder block main body, and (2) a method of fixing the group of cylinder liners to a cylinder main body through fitting (Patent Literature 1 and Patent Literature 2). In each of the methods of manufacturing a cylinder block, which are disclosed in Patent Literature 1 and Patent Literature 2, the plurality of cylinder liners are integrally formed, and the group of cylinder liners formed of one member is used.

Citation List

Patent Literature

[0003]

[PTL 1] JP 2813947 B2
[PTL 2] JP 4278125 B2

Summary of Invention

Technical Problem

[0004] Meanwhile, for an internal combustion engine, various kinds of performances are required to be satisfied in accordance with requirement specifications of a vehicle or apparatus other than the vehicle, for which the internal combustion engine is used. For this purpose, when the internal combustion engine is designed, the internal combustion engine having a higher degree of freedom in design is advantageous. Further, the internal combustion engine is also required to be excellent in maintainability. Further, in recent years, the internal combustion engine is required to have recycling efficiency in terms of an environmental load. As a result of examination by the inventors of the present invention, however, it has been found that there is difficulty in satisfying all of three requirements, specifically, the maintainability, the recycling efficiency, and the degree of freedom in design with the methods of manufacturing a cylinder block, which are disclosed in Patent Literature 1 and Patent Literature 2, and internal combustion engines manufactured by using the methods.

[0005] The present invention has been made in view of the conditions described above, and has an object to provide a method of manufacturing an internal combustion engine, which provides excellent maintainability and recycling efficiency for an internal combustion engine and a high degree of freedom in design of the internal combustion engine, an internal combustion engine manufactured by using the method, and a connected cylinder to be used therefor.

Solution to Problem

[0006] The object described above is accomplished by the following aspects of the present invention.

[0007] That is, according to one aspect of the present invention, there is provided a method of manufacturing an internal combustion engine, including at least a fitting step of fitting a connected cylinder to a hollow portion of a cylinder block main body, the connected cylinder including any one of connected cylinders selected from the group consisting of: (1) a first connected cylinder including two or more cylinder liners and a connecting portion configured to connect the two or more cylinder liners to each other; and (2) a second connected cylinder including a connected cylinder main body portion having two or more cylinder bores and a coating configured to cover an inner peripheral surface of the connected cylinder main body portion in which the cylinder bores are formed, the cylinder block main body having one end side where a crankcase is formed and another end side where a cylinder head is attachable, the hollow portion passing through the cylinder block main body from the one end side to the another end side.

[0008] According to one embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the two or more cylinder liners and the connecting portion be formed integrally and inseparably.

[0009] According to another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the connecting portion cover entire outer peripheral surfaces of the two or more cylinder liners.

[0010] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that a material that forms the connecting portion be different from a material that forms the cylinder block main body.

[0011] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that a material that forms the connected cylinder main body portion be different from a material that forms the cylinder block main body.

[0012] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the fitting step be carried out through any type of fitting selected from clearance fit, transition fit, and interference fit.

[0013] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the connected cylinder include the first connected cylinder, and that a sliding surface formation step of forming sliding surfaces by finishing inner peripheral surfaces of the cylinder liners be carried out only before the fitting step.

[0014] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the connected cylinder include the first connected cylinder, that, after a coating formation step of forming coatings on inner peripheral surfaces of the cylinder liners is carried out, a sliding surface formation step of forming sliding surfaces by finishing surfaces of the coatings be carried out, and that the sliding surface formation step be carried out only before the fitting step.

[0015] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the connected cylinder include the second connected cylinder, and that a sliding surface formation step of forming a sliding surface by finishing a surface of the coating configured to cover the inner peripheral surface of the connected cylinder main body portion in which the cylinder bores are formed be carried out only before the fitting step.

[0016] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the fitting step be carried out through any type of fitting selected from clearance fit and transition fit.

[0017] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the fitting step be carried out through clearance fit.

[0018] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the connected cylinder include the first connected cylinder, and that a sliding surface formation step of forming sliding surfaces by finishing inner peripheral surfaces of the cylinder liners be carried out only after the fitting step.

[0019] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the connected cylinder include the first connected cylinder, that, after a coating formation step of forming coatings on inner peripheral surfaces of the cylinder liners is carried out, a sliding surface formation step of forming sliding surfaces by finishing surfaces of the coatings be carried out, and that the sliding surface formation step be carried out only after the fitting step.

[0020] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the connected cylinder include the second connected cylinder, and that a sliding surface formation step of forming a sliding surface by finishing a surface of the coating configured to cover the inner peripheral surface of the connected cylinder main body portion in which the cylinder bores are formed be carried out only after the fitting step.

[0021] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the sliding surface formation step be carried out under a state in which the connected cylinder is assembled to a jig that imitates the cylinder block main body and the cylinder head, and at least the connected cylinder is heated.

[0022] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that a coolant passage formation step of forming a coolant passage between two adjacent ones of the cylinder bores of the connected cylinder be carried out at least before the fitting step.

[0023] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the coolant passage be provided inside an end surface of the connected cylinder on a side where the cylinder head is arrangeable, and that a sectional shape of the coolant passage, which is taken along a plane being parallel to a center line of each of the cylinder bores formed in the connected cylinder, be a slit-like shape.

[0024] According to still another embodiment of the present invention, in the method of manufacturing an internal combustion engine, it is preferred that the cylinder block main body be formed by any method selected from casting and resin molding.

[0025] According to one aspect of the present invention, there is provided an internal combustion engine including at least: a connected cylinder selected from the group consisting of: (1) a first connected cylinder including two or more cylinder liners and a connecting portion configured to connect the two or more cylinder liners to each other; and (2) a second connected cylinder including a connected cylinder main body portion having two or more cylinder bores and a coating configured to cover an inner peripheral surface of the connected cylinder main body portion in which the cylinder bores are formed; and a cylinder block main body having one end side where a crankcase is formed, another end side where a cylinder head is attachable, and a hollow portion passing through the cylinder block main body from the one end side to the another end side, wherein the connected cylinder is fitted to the hollow portion of the cylinder block main body so as to be removable.

[0026] According to one embodiment of the present invention, in the internal combustion engine, it is preferred that the connected cylinder be fitted into the hollow portion of the cylinder block main body through any type of fitting selected from clearance fit and transition fit.

[0027] According to another embodiment of the present invention, in the internal combustion engine, it is preferred that a coolant passage be provided between two adjacent ones of the cylinder bores of the connected cylinder so as to be located inside an end surface of the connected cylinder on which the cylinder head is arranged, and that a sectional shape of the coolant passage, which is taken along a plane being parallel to a center line of each of the cylinder bores formed in the connected cylinder, be a slit-like shape.

[0028] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that fixing flange portions be formed on an outer peripheral surface of the connected cylinder along a direction parallel to a center line of each of cylinder bores formed in the connected cylinder, and that guide grooves to be fitted to the fixing flange portions be formed in an inner peripheral surface of the hollow portion of the cylinder block main body.

[0029] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that the fixing flange portions be formed on the outer peripheral surface so as to be located on both end sides in a direction of arrangement of the cylinder bores, and that the guide grooves be formed in the inner peripheral surface of the hollow portion of the cylinder block main body so as to be located on both end sides in a longitudinal direction of an opening portion of the hollow portion.

[0030] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that fixing flange portions be formed on an inner peripheral surface of the hollow portion of the cylinder block main body along a direction parallel to a penetrating direction of the hollow portion, and that guide grooves to be fitted to the fixing flange portions be formed in an outer peripheral surface of the connected cylinder.

[0031] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that the fixing flange portions be formed on the inner peripheral surface of the hollow portion of the cylinder block main body so as to be located on both end sides in a longitudinal direction of an opening portion of the hollow portion, and that the guide grooves be formed in the outer peripheral surface of the connected cylinder so as to be located on both end sides in a direction of arrangement of cylinder bores formed in the connected cylinder.

[0032] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that the internal combustion engine include a horizontally-opposed engine.

[0033] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that a coolant jacket be provided between an outer peripheral surface of the connected cylinder and an inner peripheral surface of the hollow portion of the cylinder block main body.

[0034] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that a dividing flange portion configured to divide the coolant jacket into two or more portions be formed at least on any surface selected from the outer peripheral surface of the connected cylinder and the inner peripheral surface of the hollow portion of the cylinder block main body.

[0035] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that the fixing flange portions also have a function of the dividing flange portion.

[0036] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that the dividing flange portion have no through hole penetrating in a width direction of the dividing flange portion.

[0037] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that the dividing flange portion have a through hole penetrating in a width direction of the dividing flange portion and a closing member capable of closing the through hole.

[0038] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that the through hole be closed by the closing member when the internal combustion engine is operated.

[0039] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that no coolant jacket spacer be arranged in the coolant jacket.

[0040] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that a depth D of the coolant jacket be 1/2 times of a total length L of the coolant jacket or smaller in a direction parallel to a center line of each of cylinder bores formed in the connected cylinder.

[0041] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that a depth D of the coolant jacket be 1/2 times of a total length L of the coolant jacket or smaller in a direction parallel to a center line of each of cylinder bores formed in the connected cylinder, and that no coolant jacket spacer be arranged in the coolant jacket.

[0042] According to another embodiment of the present invention, in the internal combustion engine, it is preferred that a projecting portion be formed at least on a portion of the outer peripheral surface of the connected cylinder, which is located on the another end side (cylinder head side), and that a distal end of the projecting portion be held in close contact with a portion of the inner peripheral surface of the hollow portion of the cylinder block main body, which is located on the another end side (cylinder head side).

[0043] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that a fixing member configured to fix the connected cylinder and the cylinder block main body to each other be provided between a portion of the outer peripheral surface of the connected cylinder, which is located on the another end side (cylinder head side), and a portion of the inner peripheral surface of the cylinder block main body, which is located on the another end side (cylinder head side).

[0044] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that the first connected cylinder have a connected ring-like outer peripheral shape having a ring-like portion with a diameter larger than a bore diameter of each of the cylinder liners, that an outer diameter D1 of a first region formed of an outer peripheral surface from a vicinity of a side of the cylinder head to a vicinity of a central portion in a direction of a center line of each of the cylinder liners based on the center line of each of the cylinder liners as a reference be larger than an outer diameter D2 of a second region formed of an outer peripheral surface in a vicinity of a side of the crankcase based on the center line of each of the cylinder liners as a reference, that a level difference that is parallel to an outer peripheral direction and is continuous be formed between the first region and the second region, and that a coolant jacket be formed between the first region and the inner peripheral surface of the hollow portion of the cylinder block main body.

[0045] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that the second connected cylinder have a connected ring-like outer peripheral shape having a ring-like portion with a diameter larger than a bore diameter of each of the cylinder bores, that an outer diameter D1 of a first region formed of an outer peripheral surface from a vicinity of a side of the cylinder head to a vicinity of a central portion in a direction of a center line of each of the cylinder bores based on the center line of each of the cylinder bores as a reference be larger than an outer diameter D2 of a second region formed of an outer peripheral surface in a vicinity of a side of the crankcase based on the center line of each of the cylinder bores as a reference, that a level difference that is parallel to an outer peripheral direction and is continuous be formed between the first region and the second region, and that a coolant jacket be formed between the first region and the inner peripheral surface of the hollow portion of the cylinder block main body.

[0046] According to still another embodiment of the present invention, in the internal combustion engine, it is preferred that a flange portion that partitions the first region into a region on the cylinder head side and a region on the crankcase side be formed on the first region, and that the coolant jacket be divided by the flange portion in a direction of the center line of each of the cylinder liners or each of the cylinder bores.

[0047] According to a first aspect of the present invention, provided is a connected cylinder, including: two or more cylinder liners; and a connecting portion configured to connect the two or more cylinder liners to each other.

[0048] According to one embodiment of a first aspect of the present invention, it is preferred that the connected cylinder have a connected ring-like outer peripheral shape having a ring-like portion with a diameter larger than a bore diameter of each of the cylinder liners, that an outer diameter D1 of a first region formed of an outer peripheral surface from a vicinity of a cylinder head side to a vicinity of a central portion in a direction of a center line of each of the cylinder liners based on the center line of each of the cylinder liners as a reference be larger than an outer diameter D2 of a second region formed of an outer peripheral surface in a vicinity of a crankcase side based on the center line of each of the cylinder liners as a reference, and that a level difference that is parallel to an outer peripheral direction and is continuous be formed between the first region and the second region.

[0049] According to a second aspect of the present invention, provided is a connected cylinder, including: a connected cylinder main body portion having two or more cylinder bores; and a coating configured to cover an inner peripheral surface of the cylinder bores, which are formed in the connected cylinder main body portion.

[0050] According to one embodiment of a second aspect of the present invention, it is preferred that the connected cylinder have a connected ring-like outer peripheral shape having a ring-like portion with a diameter larger than a bore diameter of each of the cylinder bores, that an outer diameter D1 of a first region formed of an outer peripheral surface from a vicinity of a cylinder head side to a vicinity of a central portion in a direction of a center line of each of the cylinder bores based on the center line of each of the cylinder bores as a reference be larger than an outer diameter D2 of a second region formed of an outer peripheral surface in a vicinity of a crankcase side based on the center line of each of the cylinder bores as a reference, and that a level difference that is parallel to an outer peripheral direction and is continuous be formed between the first region and the second region.

[0051] According to one embodiment of the first and second aspects of the present invention, it is preferred that the connected cylinder further include a flange portion formed on an outer peripheral surface.

[0052] According to another embodiment of the first and second aspects of the present invention, in the connected cylinder, it is preferred that a flange portion that partitions the first region into a region on the cylinder head side and a region on the crankcase side be formed on the first region.

[0053] According to still another embodiment of the first and second aspects of the present invention, in the connected cylinder, it is preferred that the flange portion have no through hole penetrating in a width direction of the flange portion.

[0054] According to still another embodiment of the first and second aspects of the present invention, in the connected cylinder, it is preferred that the flange portion have a through hole penetrating in a width direction of the flange portion and a closing member capable of closing the through hole.

[0055] According to still another embodiment of the first and second aspects of the present invention, in the connected cylinder, it is preferred that a coolant passage be formed between adjacent two ones of cylinder bores of the connected cylinder so as to be located inside an end surface of the connected cylinder on a side where the cylinder head is arrangeable and that a sectional shape of the coolant passage, which is taken along a plane being parallel to a center line of each of the cylinder bores formed in the connected cylinder, be a slit-like shape.

[0056] According to another embodiment of the first and second aspects of the present invention, in the connected cylinder, it is preferred that the first region have no projecting portion.

[0057] According to still another embodiment of the first and second aspects of the present invention, in the connected cylinder, it is preferred that the second region have no projecting portion.

Advantageous Effects of Invention

[0058] According to the present invention, it is possible to provide a method of manufacturing an internal combustion engine, which provides excellent maintainability and recycling efficiency for an internal combustion engine and a high degree of freedom in design of the internal combustion engine, an internal combustion engine manufactured by using the method, and a connected cylinder to be used therefor.

Brief Description of Drawings

[0059]

FIG. 1 is an external appearance perspective view for illustrating an example of a first connected cylinder to be used for a method of manufacturing an internal combustion engine according to an embodiment of the present invention.

FIG. 2 is an enlarged perspective view of a portion of the first connected cylinder illustrated in FIG. 1, which is located on a cylinder head side.

FIG. 3 is an enlarged sectional view for illustrating an example of a sectional structure of the first connected cylinder illustrated in FIG. 2, which is taken along the line III-III.

FIG. 4 is an enlarged perspective view for illustrating an example of a portion of a second connected cylinder, which is located on the cylinder head side, to be used for the method of manufacturing an internal combustion engine according to the embodiment.

FIG. 5 is an enlarged sectional view for illustrating an example of a sectional structure of the second connected cylinder illustrated in FIG. 4, which is taken along the line V-V.

FIG. 6 is an exploded perspective view for illustrating part of a cylinder block main body in a broken manner for an example of the cylinder block main body to be used for the method of manufacturing an internal combustion engine according to the embodiment.

FIG. 7 is an external appearance perspective view for illustrating an example of an internal combustion engine using the first connected cylinder that is manufactured by the method of manufacturing an internal combustion engine according to the embodiment.

FIG. 8 is a schematic sectional view for illustrating an example of a sectional structure of the internal combustion engine illustrated in FIG. 7, which is taken along the line VIII-VIII.

FIG. 9 is a schematic sectional view for illustrating an example of a sectional structure of the first connected cylinder illustrated in FIG. 3, which is taken along the line IX-IX.

FIG. 10 is a schematic sectional view for illustrating an example of a sectional structure of the second connected cylinder illustrated in FIG. 5, which is taken along the line X-X.

FIG. 11 is a schematic sectional view for illustrating a modification example of the first connected cylinder illustrated in FIG. 9.

FIG. 12 is a schematic sectional view for illustrating a modification example of the internal combustion engine illustrated in FIG. 8.

FIG. 13 is a schematic sectional view for illustrating another modification example of the internal combustion engine illustrated in FIG. 8.

FIGS. 14 are schematic end views, each for illustrating an example of a sectional shape of a coolant passage and are specifically enlarged views for illustrating end surfaces (ZX cross section) in the vicinity of another end-side (Z1 side) of a first connected cylinder, in which FIG. 14(A) is an end view for illustrating a coolant passage having a circular sectional shape, FIG. 14(B) is an end view for illustrating a coolant passage having a slit-like sectional shape, which has an opening portion even on an end surface of the connected cylinder on the another end-side (Z1 side), FIG. 14(C) is an end view for illustrating a coolant passage having a slit-like sectional shape formed inside (on one end side (Z2 side) of) the end surface of the connected cylinder 10 on the another end-side (Z1 side).

FIG. 15 is an external appearance perspective view for illustrating another modification example of the first connected cylinder illustrated in FIG. 1.

FIG. 16 is an external appearance perspective view for illustrating still another modification example of the first connected cylinder illustrated in FIG. 1.

FIG. 17 is an external appearance perspective view for illustrating still another modification example of the first connected cylinder illustrated in FIG. 1.

FIG. 18 is a top view for illustrating an example of the cylinder block main body to be used in combination with the first connected cylinder illustrated in FIG. 15.

Description of Embodiment

[0060] A method of manufacturing an internal combustion engine, an internal combustion engine, and a connected cylinder according to this embodiment are described below with reference to the drawings. In the following description, an X direction, a Y direction, and a Z direction illustrated in the drawings are orthogonal to each other. In this case, the X direction is a direction of arrangement of cylinder bores. The Y direction is a direction orthogonal to the direction of arrangement of the cylinder bores and to center lines C of the cylinder bores (center lines C of the cylinder bores and cylinder liners in a first connected cylinder) . The Z direction is a direction parallel to the center lines C of the cylinder bores. In the X direction, an X1 side is opposite to an X2 side. In the Y direction, a Y1 side is opposite to a Y2 side. In the Z direction, a Z1 side (cylinder head side) is opposite to a Z2 side (crankcase side).

<Method of Manufacturing Internal Combustion Engine>

[0061] In the method of manufacturing an internal combustion engine according to this embodiment, there is used any one of connected cylinders selected from the group consisting of: (1) a first connected cylinder including two or more cylinder liners and a connecting portion configured to connect the two or more cylinder liners to each other; and (2) a second connected cylinder including a connected cylinder main body portion having two or more cylinder bores and coatings configured to cover inner peripheral surfaces of the connected cylinder main body portion in which the cylinder bores are formed.

[0062] FIG. 1 to FIG. 3 are schematic views for illustrating an example of a connected cylinder to be used for a method of manufacturing an internal combustion engine according to this embodiment, more specifically, views for illustrating an example of the first connected cylinder. In the drawings, FIG. 1 is an external appearance perspective view of the first connected cylinder, and FIG. 2 is an enlarged perspective view of a portion of the first connected cylinder, which is located on the cylinder head side. FIG. 3 is an enlarged sectional view for illustrating an example of a sectional structure of the portion of the first connected cylinder, which is located on the cylinder head side, and for illustrating a sectional structure (XY sectional structure) of the first connected cylinder illustrated in FIG. 2, which is taken along the line III-III.

[0063] A first connected cylinder 10A1 (10A, 10) exemplified in FIG. 1 to FIG. 3 includes four cylinder bores 20. The cylinder bores 20 are formed along the X direction so that center lines C thereof are located on the same plane (XZ plane). The first connected cylinder 10A1 includes four cylinder liners 40 and a connecting portion 42 configured to connect the four cylinder liners 40 to each other. In the example illustrated in FIG. 1 to FIG. 3, the connecting portion 42 is provided so as to cover at least entire outer peripheral surfaces 40A of the four cylinder liners 40 each having a cylindrical shape, and has a connected ring-like outer peripheral shape having ring-like portions each with a diameter obtained by increasing a bore diameter Db of each of the cylinder liners 40. One of the cylinder liners 40 and another of the cylinder liners 40, which are adjacent to each other in the X direction, are arranged to be spaced away from each other by a given distance so that the outer peripheral surfaces 40A thereof do not come into contact with each other. Specifically, a space between the two adjacent cylinder liners 40 is filled with a material that forms the connecting portion 42 without a gap. A cylinder head-side end surface and a crankcase-side end surface of each of the cylinder liners 40 are covered with the connecting portion 42. Any one or both of the cylinder head-side end surface and the crankcase-side end surface of each of the cylinder liners 40 are not required to be covered with the connecting portion 42.

[0064] FIG. 4 and FIG. 5 are schematic views for illustrating another example of the connected cylinder to be used for the method of manufacturing an internal combustion engine according to this embodiment, more specifically, views for illustrating an example of the second connected cylinder. FIG. 4 is an enlarged perspective view of a portion of the second connected cylinder, which is located on the cylinder head side. FIG. 5 is an enlarged sectional view for illustrating an example of a sectional structure of the portion of the second connected cylinder, which is located on the cylinder head side, and is a view for illustrating a sectional structure (XY sectional structure) of the connected cylinder illustrated in FIG. 4, which is taken along the line V-V.

[0065] An outer peripheral shape of a second connected cylinder 10B (10) exemplified in FIG. 4 and FIG. 5 is similar to that of the first connected cylinder 10A1 exemplified in FIG. 1. The second connected cylinder 10B also has the four cylinder bores 20. The cylinder bores 20 are arranged along the X direction so that the center lines C thereof are located on the same plane (XZ plane) . The second connected cylinder 10B includes a connected cylinder main body portion 50 having the four cylinder bores 20 and coatings 52 configured to cover inner peripheral surfaces 50B of the connected cylinder main body portion 50 in which the cylinder bores 20 are formed. In the example illustrated in FIG. 4 and FIG. 5, the connected cylinder main body portion 50 has a connected ring-like outer peripheral shape having ring-like portions each with a diameter obtained by increasing the bore diameter Db of each of the four cylinder bores 20 each having a circular hole shape.

[0066] Although the first connected cylinder 10A1 exemplified in FIG. 1 to FIG. 3 includes the four cylinder liners 40, the number of cylinder liners 40 is not particularly limited as long as the number of cylinder liners 40 is two or more. In general, the number of cylinder liners 40 can be selected within a range of from 2 to 8. Although the second connected cylinder 10B exemplified in FIG. 4 and FIG. 5 has the four cylinder bores 20, the number of cylinder bores 20 is not particularly limited as long as the number of cylinder bores 20 is two or more. In general, the number of cylinder bores 20 can be selected within a range of from 2 to 8.

[0067] With the method of manufacturing an internal combustion engine according to this embodiment, an internal combustion engine is manufactured at least through a fitting step of fitting the connected cylinder 10 as exemplified in FIG. 1 to FIG. 5 to a cylinder block main body.

[0068] As exemplified in FIG. 6, a cylinder block main body 60A (60) has a structure having one end side (Z2 side) where a crankcase 62 is formed, another end side (Z1 side) where a cylinder head is attachable, and a hollow portion 64 passing through cylinder block main body 60A (60) from the one end side to the another end side. In the fitting step, the connected cylinder 10 is fitted to the hollow portion 64. After the fitting step is carried out, various other steps are carried out to complete the internal combustion engine. As the other steps, there is given, for example, a step of assembling the cylinder head on the cylinder head side (Z1 side) of the cylinder block main body 60 in which the connected cylinder 10 fitted and fixed to the hollow portion 64 is arranged.

[0069] In the fitting step, the connected cylinder 10 can be fitted into the hollow portion 64 of the cylinder block main body 60 through any type of fitting selected from clearance fit, transition fit, and interference fit. In the specification of this application, the "clearance fit" is fitting with which a gap is generated between members to be fitted together even in consideration of a tolerance of each of the members, the "interference fit" is fitting with which an interference margin is generated between members to be fitted together even in consideration of a tolerance of each of the members, and the "transition fit" is fitting with which a gap is generated between members to be fitted in some cases and an interference margin is generated between members to be fitted in other cases in consideration of a tolerance of each of the members (intermediate fitting between the clearance fit and the interference fit).

[0070] A fitting method using the interference fit is not particularly limited. There are given, for example, cooling fit with which the connected cylinder 10 in a cooled state is fitted into the hollow portion 64 of the cylinder block main body 60, shrinkage fit with which the connected cylinder 10 is fitted into the hollow portion 64 of the cylinder block main body 60 in a heated state, and strong press-fit. A fitting method using the transition fit is not particularly limited. There are given, for example, fitting under a state in which slipping in a fitting portion is improved with use of, for example, a lubricant, fitting with use of a jig made of a material softer than the connected cylinder 10 (for example, by driving with use of a hammer made of a resin or wood) after positioning with high accuracy is performed. Further, when the connected cylinder 10 is fitted into the hollow portion 64 of the cylinder block main body 60 through the clearance fit, the fitting may be carried out under a state in which an easily deformable or flowable material including a resin material, a rubber material, a fibrous material such as glass fiber, or a paste-like material is arranged between the members as needed.

[0071] The selection of the type of fitting may be made in accordance with, for example, requirement design specifications of an internal combustion engine 100. When the connected cylinder 10 is desired to be firmly fixed to the cylinder block main body 60, the fitting through the interference fit is preferred. As a case in which the fitting through the interference fit is suitable, for example, there is exemplified a case in which the internal combustion engine 100 has such a configuration that the center lines C of the cylinder bores are generally greatly inclined with respect to or orthogonal to a vertical direction under a state in which the internal combustion engine 100 is mounted in a device such as an automobile and at the time of assembly, as in a case in which the internal combustion engine 100 is a V-type engine or a horizontally-opposed engine.

[0072] Meanwhile, under the state in which the internal combustion engine 100 is mounted in a device such as an automobile and at the time of assembly, when the internal combustion engine 100 has such a configuration that the vertical direction and the center lines C of the cylinder bores become parallel or substantially parallel to each other as in a case in which the internal combustion engine 100 is, for example, an in-line engine, it is easy to stably fix the connected cylinder 10 in the cylinder block main body 60 without causing a positional shift of the connected cylinder 10 in a direction orthogonal to the center lines C of the cylinder bores. In the case described above, the fitting through the clearance fit is also suitable. Further, even in the internal combustion engine 100 having such a configuration that the center lines C of the cylinder bores are generally greatly inclined with respect to or orthogonal to the vertical direction under a state in which the internal combustion engine 100 is mounted in a device such as an automobile, in a case in which the connected cylinder 10 is arranged so that the vertical axis and the center lines C of the cylinder bores become parallel or substantially parallel to each other at the time of assembly of the internal combustion engine 100 (particularly preferably, during a time period from a time immediately before the mounting of the connected cylinder 10 into the cylinder block main body 60 to completion of the assembly of the cylinder head), the fitting through the clearance fit is also suitable. Further, in comparison to the interference fit and the transition fit, the clearance fit is less liable to cause damage to the fitting portion between the connected cylinder 10 and the cylinder block main body 60 at the time of disassembly of the internal combustion engine 100. Thus, the clearance fit is also advantageous in terms of reuse of components.

[0073] Further, (i) when deformation of the connected cylinder 10, the cylinder bores 20, the cylinder block main body 60 or the hollow portion 64 is desired to be suppressed, or (ii) when the connected cylinder 10 is desired to be more easily removed from the cylinder block main body 60 at the time of repair and maintenance of the internal combustion engine 100 or at the time of disposal thereof, it is preferred that the fitting be achieved through the clearance fit. Further, when an intermediate effect between an effect obtained by the fitting through the interference fit and an effect obtained by the fitting through the clearance fit is desired to be obtained, the fitting through the transition fit is preferred.

[0074] Further, when the connected cylinder 10 is fitted into the hollow portion 64, it is suitable to form an outer peripheral surface 10S of the connected cylinder 10 on the one end side (Z2 side) as a tapered surface so as to improve positioning of the connected cylinder 10 with respect to the hollow portion 64 and ease of insertion thereof.

[0075] FIG. 7 is an external appearance perspective view for illustrating an example of an internal combustion engine manufactured by the method of manufacturing an internal combustion engine according to this embodiment, and FIG. 8 is a schematic sectional view for illustrating an example of a sectional structure (YZ sectional structure) of the internal combustion engine illustrated in FIG. 7, which is taken along the line IV-IV. In the internal combustion engine illustrated in FIG. 7 and FIG. 8, illustration is omitted for main components other than the connected cylinder and the cylinder block main body, which construct the internal combustion engine.

[0076] An internal combustion engine 100A (100) illustrated in FIG. 7 and FIG. 8 includes the connected cylinder 10 and the cylinder block main body 60. The connected cylinder 10 is removably fitted to a one end-side portion (fitting portion 64J) of the hollow portion 64 of the cylinder block main body 60. Although the first connected cylinder 10A1 exemplified in FIG. 1 to FIG. 3 is used as the connected cylinder 10 in the example illustrated in FIG. 7 and FIG. 8, the second connected cylinder 10B or the connected cylinder 10 having a flange portion 16 as exemplified in FIGS. 11 and 15 to 17 referred to later can be used in place of the first connected cylinder 10A1. In the example illustrated in FIG. 7 and FIG. 8, the cylinder block main body 60A is used as the cylinder block main body 60. When the connected cylinder 10 having the flange portion 16 is used, however, a cylinder block main body 60B (60) as exemplified in FIG. 13 referred to later can also be used.

[0077] Meanwhile, in a general internal combustion engine having a structure in which a plurality of cylinder liners are casted into a cylinder block, an entire main part of the internal combustion engine, which includes the cylinder liners and the cylinder block, is required to be handled even when repair and replacement work is required for only part of the internal combustion engine. In addition, in the general internal combustion engine, a plurality of, that is, two or more kinds of materials having different material properties (for example, a material that forms the cylinder liners and a material that forms the cylinder block having the cylinder liners casted therein) are formed integrally and inseparably. Therefore, when a recycling process is required to be performed for each of the kinds of materials, the materials are required to be separated for each of the kinds of materials by using a difference in melting temperature between the materials. The same applies to an internal combustion engine disclosed in Patent Literature 1, which has a structure in which a group of the cylinder liners is casted into the cylinder block main body.

[0078] Meanwhile, in the method of manufacturing an internal combustion engine according to this embodiment, as exemplified in FIG. 7 and FIG. 8, the connected cylinder 10 is fixed to the cylinder block main body 60 by fitting the connected cylinder 10 to the hollow portion 64. Therefore, even after being fixed to the cylinder block main body 60, the connected cylinder 10 can be easily removed from the cylinder block main body 60. Therefore, when the internal combustion engine 100 is subjected to maintenance, the connected cylinder 10 is removed from the cylinder block main body 60 so that any one or both of the connected cylinder 10 and the cylinder block main body 60 can be repaired or replaced individually. Therefore, the internal combustion engine 100 manufactured by the method of manufacturing an internal combustion engine according to this embodiment is excellent in maintainability.

[0079] In addition, when the internal combustion engine 100 is to be disposed of, the connected cylinder 10 and the cylinder block main body 60, which are main components constructing the internal combustion engine 100, can be easily separated so as to be disposed of separately. In this case, the cylinder block main body 60, which is to be used for the method of manufacturing an internal combustion engine according to this embodiment, is generally formed of a member (member which is entirely integral and inseparable and is made of one kind of material) produced by using casting, resin molding, or other methods.

[0080] Therefore, the cylinder block main body 60, which is removed from the internal combustion engine 100, can be directly subjected to the recycling process without being subjected to, for example, further separation process. For example, when the cylinder block main body 60 is a cast that is manufactured using an aluminum alloy, cast iron, or other materials, the cylinder block main body 60 can be subjected to a dissolution treatment to be reused. Therefore, the internal combustion engine 100 manufactured by the method of manufacturing an internal combustion engine according to this embodiment is also excellent in recycling efficiency. Although it is particularly preferred that the cylinder block main body 60 be generally formed of an entirely integral and inseparable member made of a single kind of material, a structure of the cylinder block main body 60 is not limited to that in a case in which the cylinder block main body 60 is formed of an entirely integral and inseparable member made of a single kind of material as long as the cylinder block main body 60 has substantially the same degree of recycling efficiency as that of the member described above.

[0081] When any one of the members which construct the internal combustion engine 100 to be disposed of, that is, the connected cylinder 10 and the cylinder block main body 60, is satisfactorily reusable, the one member may be reused and only another of the members may be disposed of.

[0082] In view of ease of separation and disassembly between the connected cylinder 10 and the cylinder block main body 60 at the time of recycling or disposal of the internal combustion engine 100, it is preferred that the connected cylinder 10 be fitted into the hollow portion 64 of the cylinder block main body 60 through any type of fitting selected from the clearance fit and the transition fit. It is more preferred that the fitting be achieved through the clearance fit.

[0083] Meanwhile, when the internal combustion engine 100 in which the connected cylinder 10 is fitted into the hollow portion 64 of the cylinder block main body 60 through the interference fit is to be recycled or disposed of, it is preferred that a reverse process to the cooling fit and/or the shrinkage fit be carried out. Specifically, when the connected cylinder 10 is in a cooled state and/or the cylinder block main body 60 is in a heated state, the connected cylinder 10 and the cylinder block main body 60 can easily be separated from each other and disassembled. The above-mentioned method of disassembling the internal combustion engine 100 may be applied to the internal combustion engine 100 in which the connected cylinder 10 is fitted into the hollow portion 64 of the cylinder block main body 60 through the transition fit or the clearance fit, as needed.

[0084] With a general related-art method of manufacturing an internal combustion engine in which the cylinder liners and the cylinder block are integrated by cast-in of the cylinder liners with a casting material, a whole member obtained by integrating the cylinder liners and the cylinder block is required to be disposed of even when a defect is found only in a portion of the cylinder liners or a portion in the vicinity thereof or a defect is found only in the cylinder block after casting. Meanwhile, with the method of manufacturing an internal combustion engine according to this embodiment, the two components (the connected cylinder 10 and the cylinder block main body 60) are prepared separately and are then combined to manufacture the internal combustion engine 100. Thus, even when a defective failure is found in any of the components after a fitting step, only the component in which the defective failure has been found is to be disposed of. Thus, in other words, even when a defective failure occurs, disposal loss in a manufacturing process can be reduced.

[0085] The internal combustion engine is required to satisfy various performances such as an output, fuel efficiency, and small-size and lightweight properties in accordance with requirement specifications of a vehicle or apparatus other than the vehicle, for which the internal combustion engine is used. In addition, particularly important characteristics for the internal combustion engine, such as the output and the fuel efficiency, tend to be greatly affected by a material property and a structure of a portion in the vicinity of the cylinder bores. Thus, it is important for the internal combustion engine to have a high degree of freedom in design, in particular, a high degree of freedom in design in the vicinity of a central portion (in the vicinity of the cylinder bores) of the internal combustion engine so that various performances can be flexibly satisfied.

[0086] Meanwhile, the connected cylinder 10 to be used for the method of manufacturing an internal combustion engine according to this embodiment has a main part formed of a combination of two kinds of members. Specifically, the first connected cylinder 10A has a main part formed of a combination of the cylinder liners 40 and the connecting portion 42, whereas the second connected cylinder 10B has a main part formed of a combination of the connected cylinder main body portion 50 and the coatings 52. Therefore, the various performances in accordance with the required specifications of the vehicle or the apparatus other than the vehicle, for which the internal combustion engine is used, are easily satisfied by appropriately changing the combination of material properties and shapes of the two kinds of members. In addition, even for the whole internal combustion engine 100, a main part thereof is formed of the connected cylinder 10 and the cylinder block main body 60, which are members separate from and independent of each other. Therefore, it is easy to satisfy the various performances in accordance with the required specifications of the vehicle or the apparatus other than the vehicle, for which the internal combustion engine is used, by appropriately changing the combination of material properties and shapes of the above-mentioned two kinds of members.

[0087] Thus, in comparison to a general internal combustion engine having a structure in which the cylinder liners and the cylinder block are formed integrally and inseparably by casting the cylinder liners into the cylinder block, and the internal combustion engines disclosed in Patent Literature 1 and Patent Literature 2, each having a structure in which the plurality of cylinder liners are integrally formed and the group of cylinder liners formed of one member is used, the internal combustion engine 100 manufactured by the method of manufacturing an internal combustion engine according to this embodiment has a high degree of freedom in design. Therefore, the internal combustion engine 100 can easily meet a wide variety of required specifications.

[0088] The internal combustion engine 100 is not limited to that manufactured according to specific design specifications, and can be flexibly designed based on various required specifications or technical concepts. As design examples of the internal combustion engine 100, the following design examples can be exemplified as basic technical concepts.

(Design Example 1)

[0089]

a) As the connected cylinder 10 to be used for the internal combustion engine 100, the first connected cylinder 10A is to be used.
b) As a material that forms the cylinder liners 40, a material that is excellent in sliding characteristics (wear resistance, seizing resistance, a low friction property) relative to those of the connecting portion 42 is to be used.
c) As a material that forms the connecting portion 42, a material having a low density (lightweight) and a high thermal conductivity (heat dissipation property) relative to those of the material that forms the cylinder liners 40 is to be used.

[0090] In Design Example 1, the internal combustion engine 100 excellent in sliding characteristics, lightweight property, and heat dissipation property can be provided.

(Design Example 2)

[0091]

a) As the connected cylinder 10 to be used for the internal combustion engine 100, the first connected cylinder 10A is to be used.
b) As a material that forms the connecting portion 42, a material having a large strength is to be used.

[0092] In Design Example 2, the strength of the connecting portion 42 is increased. Therefore, a reduction in thickness of the cylinder liners 40 and a reduction in thickness of a portion between two adjacent ones of the cylinder bores 20 are facilitated. Consequently, the internal combustion engine 100 can be reduced in weight. Alternatively, in a case in which the thickness of the portion between the two adjacent cylinder bores 20 is not reduced, when a cooling medium flow passage is formed between the two adjacent cylinder bores 20, a capacity of the cooling medium flow passage can be increased while the strength required for the first connected cylinder 10A is ensured. Further, deformation of the bores due to an increase in in-cylinder pressure, which is caused by engine combustion, can be prevented.

(Design Example 3)

[0093] As the connected cylinder 10 to be used for the internal combustion engine 100, the second connected cylinder 10B is to be used.

[0094] In Design Example 3, the sliding characteristics can be ensured by the coatings 52 having a such mass that is substantially negligibly smaller than that of the cylinder liners 40. Therefore, in the internal combustion engine, a mass and a volume of a portion formed of the second connected cylinder 10B can be easily significantly reduced in comparison to a structural portion in the vicinity of a portion in which the cylinder bores are arranged in array, specifically, a portion including the cylinder liners and a cast member that covers the cylinder liners in a general related-art internal combustion engine or a portion formed of the first connected cylinder 10A including the cylinder liners 40 and the connecting portion 42 that is provided so as to cover the entire outer peripheral surfaces 40A of the cylinder liners 40 as exemplified in FIG. 1 to FIG. 3. Thus, the internal combustion engine 100 can be remarkably reduced in weight and in size.

(Design Example 4)

[0095]

a) As the connected cylinder 10 to be used for the internal combustion engine 100, the first connected cylinder 10A is to be used.
b) As a material that forms the connecting portion 42 and the cylinder liners 40, a material having a large strength is to be used.
c) As a material that forms the cylinder block main body 60, a material lighter than a metal material, such as a resin material or an organic-inorganic composite material, is to be used.

[0096] In Design Example 4, the strength of the first connected cylinder 10A is increased. Thus, deformation of the bores can be suppressed even at high in-cylinder pressure. Further, the cylinder block main body 60, which forms a main part of the internal combustion engine 100, is made of a lightweight material. Thus, the whole internal combustion engine 100 can be reduced in weight.

(Design Example 5)

[0097]

a) As the connected cylinder 10 to be used for the internal combustion engine 100, the first connected cylinder 10A is to be used.
b) As a material that forms the connecting portion 42 and the cylinder liners 40, a material having a large strength is to be used.
c) The structure of the cylinder block main body 60 is to be simplified (for example, grooves 66 are to be omitted from the cylinder block main body 60A illustrated in FIG. 6).

[0098] In Design Example 5, the strength of the first connected cylinder 10A is increased. Thus, deformation of the bores can be suppressed even at high in-cylinder pressure. Further, the structure of the cylinder block main body 60 that forms a main part of the internal combustion engine 100 is simplified, and hence productivity of the internal combustion engine 100 is improved.

[0099] Next, the connected cylinder 10 and the cylinder block main body 60, which are to be used for the method of manufacturing an internal combustion engine according to this embodiment, are described.

[0100] First, in the first connected cylinder 10A, the two or more cylinder liners 40 and the connecting portion 42 may be formed integrally and inseparably (in other words, irremovably), or may be formed so as to be removable from each other. (a) When the first connected cylinder 10A is formed as such a member that two or more cylinder liners 40 and the connecting portion 42 are formed integrally and inseparably, an interface (joint interface) for joining both of the members to each other is formed between each of the cylinder liners 40 and the connecting portion 42. (b) When the first connected cylinder 10A is formed as such a member that two or more cylinder liners 40 and the connecting portion 42 are formed so as to be removable from each other, an interface (contact interface) at which both of the members are merely held in contact with each other is formed between each of the cylinder liners 40 and the connecting portion 42. In any of the cases (a) and (b), each of the cylinder liners 40 and the connecting portion 42 are members discontinuous with each other. Further, the connecting portion 42 may be provided so as to cover the entire outer peripheral surfaces 40A of the cylinder liners 40 as exemplified in FIG. 1 to FIG. 3, or may be provided so as to cover only part of the outer peripheral surfaces 40A of the cylinder liners 40. A selection and a combination of the above-mentioned modes can be appropriately selected in accordance with the required specifications of the internal combustion engine 100 to be manufactured.

[0101] For example, by a) a method of arranging the two or more cylinder liners 40 in the die and then pouring a molten metal into the die to cast the two or more cylinder liners 40 with a casting material such as cast iron or an aluminum alloy, or by b) resin molding for injecting or pouring a resin material in a molten state into the die after arranging the two or more cylinder liners 40 in the die, the first connected cylinder 10A in which the two or more cylinder liners 40 and the connecting portion 42 are formed integrally and inseparably can be obtained. In this case, through appropriate selection of a shape of the die, the connecting portion 42 can cover the entire outer peripheral surfaces 40A of the cylinder liners 40 and can also cover only part of the outer peripheral surfaces 40A of the cylinder liners 40.

[0102] The connecting portion 42 has two or more circular through holes, and the cylinder liners 40 are fitted and fixed to the through holes of the connecting portion 42 having the connected ring shape in which center lines of the through holes are parallel to each other. As a result, the first connected cylinder 10A in which the two or more cylinder liners 40 and the connecting portion 42 are formed so as to be removable from each other can also be obtained. In this case, for example, through appropriate selection of a length of the connecting portion 42 in a direction of the center lines, the connecting portion 42 can cover the entire outer peripheral surfaces 40A of the cylinder liners 40 and can also cover only part of the outer peripheral surfaces 40A of the cylinder liners 40.

[0103] However, it is preferred that the connecting portion 42 be formed by casting (for example, die casting and gravity molding) rather than by using a member that is formed in advance to have a connected ring shape. In this case, the number of components can be reduced at the time of manufacture of the first connected cylinder 10A. In addition, as compared to a case in which the member that is formed in advance to have the connected ring shape is used as the connecting portion 42, a heat transfer resistance at interfaces between the connecting portion 42 and the cylinder liners 40 can be reduced in a case in which the connecting portion 42 is formed integrally with and inseparably from the cylinder liners 40 by casting. Thus, it is easy to improve cooling performance of the internal combustion engine 100. When the connecting portion 42 is formed by the casting, a protrusion having a height falling within a range of from about 0.1 mm to about 1.5 mm may be formed on, or a groove or a recessed portion having a depth falling within a range of from about 0.1 mm to about 1.5 mm may be formed in the outer peripheral surface 40A of the cylinder liner 40 so as to improve joint strength between the connecting portion 42 and the cylinder liner 40.

[0104] A thickness of each of the cylinder liners 40 can be appropriately selected and generally falls within a range of from about 1.5 mm to about 4.0 mm. Moreover, more preferred shape and structure of the connected cylinder 10 are described later.

[0105] Meanwhile, for the second connected cylinder 10B, for example, after the connected cylinder main body portion 50 is produced by casting, the coatings 52 are film-formed so as to cover the inner peripheral surfaces 50B of the connected cylinder main body portion 50, in which the cylinder bores 20 are formed. For the film formation of the coatings 52, a commonly known film-formation method such as a spraying method can be appropriately used. A thickness of each of the coatings 52 can be appropriately selected and generally falls within a range of from about 0.02 mm to about 0.2 mm. In this case, when, for example, the spraying method is adopted as the film-formation method for the coatings 52, it is preferred that the thickness of each of the coatings 52 fall within a range of from about 0.1 mm to about 0.2 mm. When a physical vapor deposition (PVD) method or a chemical vapor deposition (CVD) method is adopted as the film-formation method for the coatings 52, it is preferred that the thickness of each of the coatings 52 fall within a range of from about 0.02 mm to about 0.03 mm.

Further, a plating method may be used as the film-formation method for the coatings 52. In this case, it is preferred that the thickness of each of the coatings 52 fall within a range of from about 0.02 mm to about 0.2 mm. Further, as each of the coatings 52, which is formed of a plated film, there can be given, for example, a Cr-based plated coating and a plated coating containing Ni and SiC (so-called nickel silicon carbide composite plated coating).

[0106] Although a material that forms the connecting portion 42 may be the same as a material that forms the cylinder block main body 60 in the first connected cylinder 10A, it is particularly preferred that the material that forms the connecting portion 42 be different from the material that forms the cylinder block main body 60. Similarly, although a material that forms the connected cylinder main body portion 50 may be the same as the material that forms the cylinder block main body 60 in the second connected cylinder 10B, it is particularly preferred that the material that forms the connected cylinder main body portion 50 be different from the material that forms the cylinder block main body 60.

[0107] In the specification of this application, as "two kinds of materials different from each other", there are exemplified: a) a case in which compositions of the respective materials are fundamentally different, as in the case of an aluminum alloy and steel, b) a case in which, for materials based on the same composition, for example, for two kinds of aluminum alloys, quantitative compositions are different as in a case in which one aluminum alloy contains a larger amount of Al and another of the aluminum alloys contains a smaller amount of Al, c) a case in which, for materials which are based on the same composition and have the same quantitative composition, there is a difference in crystalline-amorphous degree, in kind of crystalline phase, or in other organizational structure between one of the materials and another of the materials, or d) a case in which, although one of the materials and another of the materials contain the same substance X, one of the materials is a single material containing only the substance X and another of the materials is a composite material containing another substance Y in addition to the substance X as in a case of a plastic and a fiber-reinforced plastic.

[0108] A material different from the material that forms the cylinder block main body 60 is used as a material that forms a main part of the connected cylinder 10 (the connecting portion 42 in the first connected cylinder 10A, the connected cylinder main body portion 50 in the second connected cylinder 10B). As a result, the degree of freedom in design of the whole internal combustion engine 100 can be further improved. Therefore, it becomes extremely easy to manufacture the internal combustion engine 100 having various specifications as exemplified in the following items (1) to (3).

(1) The internal combustion engine 100 having such specifications that the cylinder block main body 60 is reduced in cost and weight, which is achieved by using a material having a high rigidity relative to that of the cylinder block main body 60 as the material that forms a main part of the connected cylinder 10.

(2) The internal combustion engine 100 having specifications with a reduced burden on a cooling system under a high load, which is achieved by using a material having a high thermal conductivity relative to that of the main part of the connected cylinder 10 as the material that forms the cylinder block main body 60.

(3) The internal combustion engine 100 having specifications with improved fuel efficiency, which is achieved by advancing a temperature rise of a coolant under a low load and warm-up by using a material having a low thermal conductivity relative to that of the main part of the connected cylinder 10 as the material that forms the cylinder block main body 60.

[0109] As a material that forms the connecting portion 42 or the connected cylinder main body portion 50, there is given, for example, a metal material such as an aluminum alloy (preferably, a high rigidity type aluminum alloy), a magnesium alloy, or steel. As a material that forms the cylinder block main body 60, there is given, for example, a metal material such as an aluminum alloy or a magnesium alloy, a resin material, or an organic-inorganic composite material containing a resin and an inorganic material (for example, a material obtained by dispersing an inorganic filler such as glass fiber or carbon fiber in a heat-resistant resin matrix such as a phenolic resin).

[0110] Further, in view of suppression of deformation of the cylinder bores 20 at the time of operation of the internal combustion engine 100, it is preferred that a thermal expansion coefficient of the material that forms the cylinder block main body 60 be equal to or larger than a thermal expansion coefficient of the material that forms the connecting portion 42 of the first connected cylinder 10A and that the thermal expansion coefficient of the material that forms the cylinder block main body 60 be equal to or larger than a thermal expansion coefficient of the material that forms the connected cylinder main body portion 50 of the second connected cylinder 10B.

[0111] As the material that forms the cylinder liners 40, there is exemplified a cast iron material such as flake graphite cast iron. As the material that forms the coatings 52, various commonly known hard materials can be used without restriction. For example, when the coatings 52 are film-formed by the spraying method, there are exemplified Fe-based materials and WC-based materials. When the coatings 52 are film-formed by the PVD method or the CVD method, there are exemplified C-based materials and Cr-based materials. Further, a layer structure of each of the coatings 52 is not particularly limited, and may be, for example, a single-layer structure or may be a laminate structure formed by combining different kinds of materials or different kinds of crystal phases.

[0112] Meanwhile, a structure of the cylinder block main body 60 to be used for the method of manufacturing an internal combustion engine according to this embodiment is not particularly limited as long as the cylinder block main body 60 has such a structure having one end side where the crankcase 62 is formed and another end side where the cylinder head is attachable, and the hollow portion 64 passing through the cylinder block main body 60 from the one end side to the another end side so that the connected cylinder 10 can be fitted to the hollow portion 64, as exemplified in FIG. 6 to FIG. 8. Further, although the cylinder block main body 60 can be manufactured by appropriately using a commonly known method, it is preferred that the cylinder block main body 60 be manufactured by casting or resin molding. As a specific example of the manufacturing method other than the casting and the resin molding, there are exemplified a hot-pressing process or a hot isostatic pressing (HIP) process, which uses base powder, and a laser sintering process of alternately repeating lamination of layers made of base powder and laser sintering. In this case, the manufacture of the cylinder block main body 60 by the casting or the resin molding has advantages described below.

[0113] First, when the member is manufactured by the casting, volume contraction occurs in a process of cooling the molten metal poured into the die. Therefore, as a volume of the member increases, a defect such as formation of a blowhole is liable to occur. Meanwhile, as compared to the related-art method of manufacturing an internal combustion engine, in which the cylinder block is formed by casting the cylinder liners with the aluminum alloy or other materials, the internal combustion engine 100 is manufactured by mechanically fitting the connected cylinder 10 and the cylinder block main body 60, which have been manufactured individually and independently of each other, with the method of manufacturing an internal combustion engine of this embodiment. Therefore, as compared to a volume of a cylinder block of a related-art internal combustion engine, the volume of the cylinder block main body 60 can be significantly reduced. Thus, when the cylinder block main body 60 is manufactured by the casting, it becomes easy to prevent occurrence of the defect such as formation of the blow hole, which is caused by the volume contraction. In addition, in comparison to the case in which the cylinder block of the related-art internal combustion engine is casted, various countermeasures (for example, keeping a thickness of the member manufactured by the casting as constant as possible) against the defects described above are not required to be actively adopted. Therefore, the degree of freedom in design can be further increased for the shape, the structure, and a casting process of the cylinder block main body 60. For example, as compared to a coolant jacket provided to the cylinder block for the related-art internal combustion engine, it is significantly easy to form the coolant jacket having a smaller depth from the another end side when the coolant jacket is provided to the cylinder block main body 60 or when the coolant jacket is provided between an inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60 and an outer peripheral surface 10S of the connected cylinder 10. The same substantially applies even to a case in which the cylinder block main body 60 is manufactured by the resin molding with which the volume contraction occurs in a process of cooling a resin material in a molten state, which is injected or poured into the die.

[0114] In the method of manufacturing an internal combustion engine according to this embodiment, various steps other than the fitting step, such as a step of assembling various components such as the cylinder head after the connected cylinder 10 is mounted to the cylinder block main body 60, a sliding surface formation step of forming a sliding surface through finishing of the inner peripheral surfaces of the cylinder bores 20, such as honing, lapping, or dimple formation, or a step of forming the coolant passage between two adjacent ones of the cylinder bores 20 in the connected cylinder 10 can be appropriately carried out as needed.

[0115] In the specification of this application, the "sliding surface" corresponds to a surface that slides in contact with a piston or a piston ring mounted in a groove formed in an outer peripheral surface of the piston when the internal combustion engine 100 in a completed state is operated. Further, once the formation of the sliding surface is completed in a manufacturing process of the internal combustion engine 100 according to this embodiment, the sliding surface is not subjected to further finishing. The sliding surface may be formed for any purpose as long as the surface slides in contact with the piston or the piston ring mounted in the groove formed in the outer peripheral surface of the piston when the internal combustion engine 100 in a completed state is operated. For example, the sliding surface may be formed incidentally and inevitably along with, for example, (a) finishing that is conducted for correction of the deformation of the cylinder bores 20 as a main purpose, or (b) finishing that is conducted for adjustment of the thickness of the cylinder liner 40 or the film thickness of each of the coatings 52 as a main purpose. However, it is preferred that the sliding surface be a surface that is finished for, for example, improvement and enhancement of seizing resistance and reduction of an oil consumption amount as main purposes.

[0116] The sliding surface may be formed by performing processing only once on each of the inner peripheral surfaces of the cylinder bores 20 or may be formed by performing processing thereon for a plurality of times . When the sliding surface is formed by performing processing for the plurality of times, the "sliding surface" corresponds only to a surface that is formed after the last finishing is performed. A step of performing the last finishing is referred to as "sliding surface formation step" . Further, a step of performing the processing (from first processing to processing second to last finishing) other than the last finishing is referred to as "roughly finished surface formation step".

[0117] The sliding surface has various surface geometries depending on a finishing method, and the surface geometries are not particularly limited. For a surface shape, for example, there is given a cross-hatched shape (surface on which net-like thin streaks or grooves or oblique-parallel linear thin streaks or grooves are formed) . For a surface roughness, there is exemplified an arithmetic average roughness Ra falling within a range of from about 0.1 μm to about 0.8 μm.

[0118] The sliding surface formation step of forming the sliding surfaces by finishing inner peripheral surfaces 20B of the cylinder bores 20 can be carried out at freely-selected timing in the manufacturing process of the internal combustion engine 100. The timing of carrying out the sliding surface formation step is roughly classified as: (I) the sliding surface formation step carried out before the fitting step; and (II) the sliding surface formation step carried out after the fitting step. In each of the processes (I) and (II) described above, another step may be carried out between the fitting step and the sliding surface formation step as needed.

[0119] (I) As a case in which the sliding surface formation step is carried out before the fitting step, for example, the following three modes are given. First, when the connected cylinder 10 is the first connected cylinder 10A, (Ia) the sliding surface formation step of forming the sliding surface by finishing each of the inner peripheral surfaces 40B of the cylinder liners 40 is carried out only before the fitting step, or (Ib) after a coating formation step of forming a coating on each of the inner peripheral surfaces 40B of the cylinder liners 40 is carried out, the sliding surface formation step of forming the sliding surface by finishing a surface of the coating can be carried out, and the sliding surface formation step can be carried out only before the fitting step. When the connected cylinder 10 is the second connected cylinder 10B, (Ic) the sliding surface formation step of forming the sliding surface by finishing a surface 52B of each of the coatings 52 that cover the inner peripheral surfaces 50B of the connected cylinder main body portion 50 in which the cylinder bores 20 are formed can be carried out only before the fitting step.

(I) In the case in which the sliding surface formation step is carried out before the fitting step, it is preferred that the fitting step be carried out through the type of fitting other than the interference fit, more specifically, through the clearance fit or the transition fit. When the fitting step is carried out through the interference fit, the cylinder bores 20 of the connected cylinder 10 are liable to be deformed. Consequently, gastightness between the piston and the sliding surface of the cylinder bore 20 is liable to be insufficient. Besides, there is an increased possibility that the sliding surface formation step may be required to be carried out again after the fitting step for correction of the deformation of the cylinder bores 20 as an additional purpose. In order to reliably prevent the above-mentioned problems, it is particularly preferred that the fitting step be carried out through the clearance fit.

(II) As a case in which the sliding surface formation step is carried out after the fitting step, for example, the following three modes are given. First, when the connected cylinder 10 is the first connected cylinder 10A, (IIa) the sliding surface formation step of forming the sliding surface by finishing each of the inner peripheral surfaces 40B of the cylinder liners 40 is carried out only after the fitting step, or (IIb) after a coating formation step of forming a coating on each of the inner peripheral surfaces 40B of the cylinder liners 40 is carried out, the sliding surface formation step of forming the sliding surface by finishing a surface of the coating can be carried out, and the sliding surface formation step can be carried out only after the fitting step. When the connected cylinder 10 is the second connected cylinder 10B, (IIc) the sliding surface formation step of forming the sliding surface by finishing the surface 52B of each of the coatings 52 that cover the inner peripheral surfaces 50B of the connected cylinder main body portion 50 in which the cylinder bores 20 are formed can be carried out only after the fitting step.

[0120] In this case, when the sliding surface is formed by performing the processing on the inner peripheral surface of each of the cylinder bores 20 for a plurality of times, the roughly finished surface formation step may be carried out before the fitting step, or may be carried out after the fitting step, or may be partially carried out before the fitting step so as to carry out the remaining part after the fitting step.

[0121] In the general related-art internal combustion engine in which the cylinder block is formed by cast-in of the cylinder liners with a casting material, the sliding surface formation step is carried out after the cylinder block is formed by cast-in of the cylinder liners with a casting material. Therefore, when the sliding surface is inspected after the sliding surface formation step is carried out, and the sliding surface is determined as defective as a result of inspection, the whole cylinder block in which the cylinder liners are cast is required to be disposed of.

[0122] Meanwhile, (I) in the case in which the sliding surface formation step is carried out before the fitting step, the sliding surface formation step is carried out for the connected cylinder 10 alone. Therefore, when the sliding surface is inspected after the sliding surface formation step is carried out, and the sliding surface is determined as defective as a result of inspection, the connected cylinder 10 alone is required to be disposed of. Therefore, even when a defective failure occurs, disposal loss in the manufacturing process can be reduced.

[0123] (I) In the case in which the sliding surface formation step is carried out before the fitting step, the sliding surface formation step may be directly carried out for the connected cylinder 10 alone. However, the sliding surface formation step may be carried out under a state in which the connected cylinder 10 is assembled to a jig that imitates the cylinder block main body 60 and the cylinder head. When the cylinder head is further assembled to the internal combustion engine 100 under a state in which the connected cylinder 10 is fitted to the cylinder block main body 60, the cylinder bores 20 are liable to be deformed at the time of assembly of the cylinder head. Therefore, when the sliding surface formation step is carried out using the jig in consideration of the deformation described above, it becomes easy to increase processing accuracy of the sliding surface.

[0124] Further, when the sliding surface formation step is carried out using the jig, it is preferred that the sliding surface formation step be carried out under a state in which at least the connected cylinder 10 is heated, and more preferably, under a state in which the connected cylinder 10 and the jig are heated. As a result, after a state in which the member has a temperature close to that during the operation is achieved, an optimal sliding surface shape can be formed. It is particularly preferred that a temperature of the member to be heated in this case be as close as an average temperature during the operation of the internal combustion engine 100. A heating method is not particularly limited. There is given, for example, a method of carrying out the sliding surface formation step under a state in which hot water (for example, hot water having a temperature falling within a range of from 30 degrees to 95 degrees) is caused to flow in the coolant jacket. As the coolant jacket used in this case, there is given, for example, (i) a coolant jacket formed in the connected cylinder 10, (ii) a (simulated) coolant jacket formed between the outer peripheral surface of the connected cylinder 10 and an inner peripheral surface of the jig that imitates the cylinder block main body 60, or (iii) a (simulated) coolant jacket formed in the jig that imitates the cylinder block main body 60.

[0125] Whether the sliding surface formation step is carried out before or after the fitting step can be appropriately selected in accordance with the whole manufacturing process of the internal combustion engine 100, specifications of the internal combustion engine 100, and other conditions. For example, when the connected cylinder 10 or the cylinder block main body 60, which has high dimensional accuracy and high strength and is less liable to be deformed, is used for the manufacture of the internal combustion engine 100 or a pressing force that may cause deformation of the cylinder bores 20 is less liable to be applied at the time of assembly of the cylinder head, (I) the sliding surface formation step is carried out before the fitting step. In an opposite case, (II) the sliding surface formation step may be carried out after the fitting step.

[0126] When cooling capability for portions of the internal combustion engine 100 to be manufactured, which are located at the periphery of the cylinder bores 20, is desired to be improved, it is preferred to carry out a coolant passage formation step of forming the coolant passage between two adjacent ones of the cylinder bores 20 of the connected cylinder 10. In this case, although the coolant passage formation step may be carried out after the fitting step, it is more preferred to carry out the coolant passage formation step before the fitting step. In any of the cases, another step may be carried out between the coolant passage formation step and the fitting step as needed. In the coolant passage formation step, the coolant passage can be formed by using, in addition to a drill, which is generally and commonly used processing means, various kinds of processing means such as a water jet, a laser, an endmill, and a cutter.

[0127] Thus, in comparison to (i) a case in which the coolant passage formation step is carried out after the fitting step or (ii) a case in which the coolant passage formation step is carried out in the related-art method of manufacturing an internal combustion engine, with which the cylinder block is formed by cast-in of the cylinder liners with a casting material, a degree of freedom in processing and formation of the coolant passage can be increased in the case in which the coolant passage formation step is carried out before the fitting step. The reason is as follows. In the above-mentioned cases (i) and (ii), when the coolant passage is formed, the digging can be started only on the cylinder head side in order to form the coolant passage. Meanwhile, in the case in which the coolant passage formation step is carried out before the fitting step, the digging can be started on any of the cylinder head side (a cylinder-head side end surface side of the connected cylinder 10) and a side (the outer peripheral surface 10S of the connected cylinder 10) other than the cylinder head side. Further, a degree of freedom in selection of a digging direction is large, and hence the processing means other than the drill, which is generally used processing means, is easily used.

[0128] Thus, when a cooling design for the periphery of the cylinder bores 20 is made, it becomes easy to achieve a more ideal design. For example, a coolant passage, which is generally impossible to form in the cases (i) and (ii) described above, specifically, a coolant passage extending in parallel to the cylinder head-side end surface of the connected cylinder 10, can be formed. Further, as a sectional shape of the coolant passage taken along a plane (ZX plane) being parallel to the center line C of each of the cylinder bores 20 formed in the connected cylinder 10, various shapes other than a simple circular shape of a coolant passage 30A (30) as illustrated in FIG. 14(A) may be selected. For example, a coolant passage having a slit-like sectional shape with the following ratio may be used. A ratio (Lz/Lx) of a maximum width Lz in a direction parallel to the center line C (Z direction) to a maximum width Lx in the direction of arrangement of the cylinder bores 20 (X direction) is larger than 1. It is preferred that the ratio (Lz/Lx) be set to fall within a range of, for example, from 2 to 10, more preferably, from 2.5 to 8. Further, values of Lz and Lx are not particularly limited. It is preferred that Lz fall within a range of, for example, from 5 mm to 30 mm and Lx fall within a range of, for example, from 2 mm to 4 mm.

[0129] As the coolant passage 30 having the slit-like sectional shape described above, there is also given, for example, (a) a coolant passage 30B (30) having an opening portion 34 being continuous in the Y direction, even on an end surface 36 of the connected cylinder 10 on the another end side (Z1 side) (FIG. 14 (B)), or (b) a coolant passage 30C (30) formed inside (on one end side (Z2 side)of) an end surface of the connected cylinder 10 on the another end side (Z1 side; the side where the cylinder head is arrangeable) (FIG. 14 (C)). When the coolant passage 30C having the slit-like sectional shape as exemplified in FIG. 14(C) is formed (a) inside (on the one end side (Z2 side) of) the end surface 36 of the connected cylinder 10 on the another end side (Z1 side), a degree of freedom in cooling design of the surroundings of the cylinder bores 20 can be further increased. When the coolant passage 30C having the slit-like sectional shape as exemplified in FIG. 14 (C) is formed, it is preferred that the coolant passage formation step be carried out at least before the fitting step. This is because, with the above-mentioned order of steps, an extremely high degree of freedom in selection of the processing means and the processing method, which are required to form the coolant passage 30C, is achieved.

[0130] In a case in which a processing error of the coolant passage 30 occurs, a target to be disposed of may be only the connected cylinder 10 regardless of timing of carrying out the coolant passage formation step, specifically, before or after the fitting step, in comparison to the case (ii) described above. Therefore, the disposal loss caused by the processing error can be reduced.

[0131] Although the coolant passage 30 is required to be formed between two adjacent ones of the cylinder bores 20, the coolant passage 30 is generally formed in a region (a region M1 illustrated in FIG. 3 and FIGS. 14) between the outer peripheral surfaces 40A of two adjacent ones of the cylinder liners 40 in the first connected cylinder 10A, and is generally formed in a region (a region M2 illustrated in FIG. 5) between outer peripheral side surfaces 52A of the coatings 52 that form the inner peripheral surfaces 20B of two adjacent ones of the cylinder bores 20 in the second connected cylinder 10B.

<Internal Combustion Engine, Connected Cylinder, and Cylinder Block Main Body>

[0132] More suitable shapes and structures of the internal combustion engine 100 to be manufactured by the method of manufacturing an internal combustion engine according to this embodiment, and the connected cylinder 10 and the cylinder block main body 60 to be used therefor are now described below. The internal combustion engine 100 to be manufactured by the method of manufacturing an internal combustion engine according to this embodiment includes, as exemplified in FIG. 7 and FIG. 8, at least the connected cylinder 10 and the cylinder block main body 60, and has a structure in which the connected cylinder 10 is fitted to the hollow portion 64 of the cylinder block main body 60 so as to be removable.

[0133] In the internal combustion engine 100 according to this embodiment, the coolant jacket provided so as to surround an outer peripheral side of the cylinder bores 20 can be provided (i) in the connected cylinder 10 (inside of the outer peripheral surface 10S of the connected cylinder 10), (ii) between the outer peripheral surface 10S of the connected cylinder 10 and the inner peripheral surface 64S of the hollow portion of the cylinder block main body 60, or (iii) in the cylinder block main body 60 (on an outer peripheral side of the inner peripheral surface 64S of the hollow portion 64) . In the case (i) described above, however, the coolant jacket is provided to the connected cylinder 10. Therefore, a structure of the connected cylinder 10 is complicated. In the case (ii) described above, the coolant jacket is provided to the cylinder block main body 60. Therefore, a structure of the cylinder block main body 60 is complicated. Thus, it is preferred that the coolant jacket be provided between the connected cylinder 10 and the cylinder block main body 60. Further, manufacturability is liable to be reduced due to complication of the structure. Therefore, it is preferred that no coolant jacket be provided in the connected cylinder 10

[0134] Meanwhile, in the case (ii) described above, as compared to the related-art internal combustion engine in which the cylinder block including the coolant jacket provided in the cylinder block is formed by cast-in of the cylinder liners with a casting material, a die having a complicated shape is not required to be used for the manufacture of the internal combustion engine 100. Therefore, the manufacturability of the internal combustion engine 100 is improved.

[0135] Further, in the internal combustion engine 100 according to this embodiment, a coolant jacket spacer may be further arranged in the coolant jacket as needed so as to bring a state of flow of the coolant in the coolant jacket closer to an ideal state to achieve a desired state of a temperature distribution on the sliding surfaces of the cylinder bores 20. Even in the above-mentioned case (ii), any of a first mode in which the coolant jacket spacer is arranged in the coolant jacket and a second mode in which the coolant jacket spacer is not arranged in the coolant jacket may be selected, and the second mode is more suitable. The reason is as follows. Specifically, a shape and a depth of the coolant jacket are determined based on a shape of the outer peripheral surface 10S of the connected cylinder 10 and the inner peripheral surface 64S of the hollow portion of the cylinder block main body 60. The connected cylinder 10 and the cylinder block main body 60 are separate and independent members . Thus, a degree of freedom in design of the shapes of both of the members is extremelyhigh. Accordingly, adegreeof freedomindesign of the shape and the depth of the coolant jacket is also extremely high. Thus, even in the second mode, it is extremely easy to bring the state of flow of the coolant in the coolant jacket closer to an ideal state so as to achieve a desired state of the temperature distribution on the sliding surfaces of the cylinder bores 20. Further, with the selection of the second mode, a reduction in the number of components that form the internal combustion engine 100 and simplification of the structure of the internal combustion engine 100 can also be achieved.

[0136] When the coolant jacket is provided between the outer peripheral surface 10S of the connected cylinder 10 and the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60, as exemplified in FIG. 8, a coolant jacket 70 is provided between another end side (cylinder head side) of the outer peripheral surface 10S of the connected cylinder 10 and another end side (cylinder head side) of the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60. Further, when being brought into contact with each other, one end side of the outer peripheral surface 10S of the connected cylinder 10 and one end side of the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60 serve as a portion in which the connected cylinder 10 is fitted to one end-side portion (fitting portion 64J) of the hollow portion 64 of the cylinder block main body 60 so as to be removable.

[0137] In any of the cases (i) to (iii) described above, a depth D (length in the Z direction) of the coolant jacket 70 is not particularly limited and can be appropriately selected in accordance with design specifications of the internal combustion engine 100. When a total length L of the connected cylinder 10 in a direction of the center line C of each of the cylinder bores 20 formed in the connected cylinder 10 is used as a reference, for example, the depth D can be appropriately selected to fall within a range of from about 1/6 times to about 5/6 times of the total length L. For example, in the case of the internal combustion engine 100 having specifications for selectively and intensively cooling portions of the cylinder bores 20, which are located on the cylinder head side, the depth D can be set to fall within a range of from 1/6 times to 1/2 times, from 1/6 times to 1/3 times, or from 1/6 times to 1/4 times of the total length L. In view of ease of formation of the shallow coolant jacket 70 having the depth D being 1/2 times of the total length L or smaller, the case (ii) is the most suitable among the cases (i) to (iii) described above. Further, when the state of the flow of the coolant in the coolant jacket 70 is desired to be brought closer to the ideal state without arranging the coolant jacket spacer in the coolant jacket 70, it is preferred that the shallow coolant jacket 70 having the depth D being 1/2 times of the total length L or smaller be formed.

[0138] A sealing member, for example, an O-ring is arranged between the inner peripheral surface 64S of the fitting portion 64J and the outer peripheral surface 10S of the connected cylinder 10, which is opposed to the inner peripheral surface 64S of the fitting portion 64J, so as to prevent a coolant (such as water) in the coolant jacket 70 from leaking toward the crankcase 62. A groove that is continuous in a circumferential direction may be formed, as needed, at least in one surface selected from the inner peripheral surface 64S of the fitting portion 64J and the outer peripheral surface 10S of the connected cylinder 10, which is opposed to the inner peripheral surface 64S of the fitting portion 64J, and the sealing member may be mounted in the groove.

[0139] In order to improve strength and prevent deformation of the cylinder head side of the cylinder bores 20 and to improve reliability of the internal combustion engine 100 at the time of high supercharging, (a1) a projecting portion may be formed at least on a portion of the outer peripheral surface 10S of the connected cylinder 10, which is located on the another end side, and a distal end portion of the projecting portion may be brought into substantially close contact with a portion of the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60, which is located on the another end side. From a similar point of view, (a2) the projecting portion may be formed at least on a portion of the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60, which is located on the another end side. Alternatively, as exemplified in FIG. 7 and FIG. 8, (b) a fixing member 80 configured to fix the connected cylinder 10 and the cylinder block main body 60 to each other may be provided between the outer peripheral surface 10S of the connected cylinder 10, which is located on the another end side, and the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60, which is located on the another end side. In view of easier manufacture of the connected cylinder 10, it is more desired to use the fixing member 80 than to form the projecting portion on the outer peripheral surface 10S of the connected cylinder 10 or the inner peripheral surface 64S of the cylinder block main body 60.

[0140] As exemplified in the items (a1) and (a2) described above, when a fitting portion is formed between another end-side portion of the connected cylinder 10 and another end-side portion of the cylinder block main body, a type of fitting for the fitting portion may be any type of fitting selected from the clearance fit, the transition fit, and the interference fit. Further, as exemplified in the item (b), when a first fitting portion is formed between the another end-side portion of the connected cylinder 10 and the fixing member 80 and a second fitting portion is formed between the another end-side portion of the cylinder block main body 60 and the fixing member 80, a type of fitting for the first fitting portion and the second fitting portion may be any type of fitting selected from the clearance fit, the transition fit, and the interference fit. In terms of suppression of the deformation of the cylinder bores 20 at the time of assembly of the internal combustion engine 100, the clearance fit or the transition fit is preferred, and the clearance fit is particularly preferred. The type of fitting described above is particularly suitable (I) in the case in which the process of carrying out the sliding surface formation step before the fitting step is employed at the time of assembly of the internal combustion engine 100.

[0141] When the fixing member 80 is used, a groove 12 may be formed in the outer peripheral surface 10S of the connected cylinder 10, which is located on the another end side, as exemplified in FIG. 1, FIG. 2, FIG. 4, and FIG. 8, and a groove 66 may also be formed in the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60, which is located on the another end side, at a position corresponding to the groove 12 formed in the outer peripheral surface 10S of the connected cylinder 10 as exemplified in FIG. 6 and FIG. 8 so as to prevent the fixing member 80 from being shifted from a predetermined position. In this case, one end of the fixing member 80 is fitted to the groove 12, and another end thereof is fitted to the groove 66. In this manner, the fixing member 80 can be arranged between the outer peripheral surface 10S of the connected cylinder 10 and the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60. The groove 12 may be formed in the connected cylinder 10 in advance, and the groove 66 may also be formed in the cylinder block main body 60 in advance. However, it is preferred to form the grooves 12 and 66 after the connected cylinder 10 in which the groove 12 has not been formed and the cylinder block main body 60 in which the groove 66 has not been formed are fitted together.

[0142] In the example illustrated in FIG. 8, a sectional shape of the fixing member 80 is rectangular. Both of an interface (first interface) between the fixing member 80 and the connected cylinder 10 and an interface (second interface) between the fixing member 80 and the cylinder block main body 60 are parallel to the center line C of the cylinder bore 20. Thus, even in a case in which the fixing member 80 is arranged between the connected cylinder 10 and the cylinder block main body 60 through the clearance fit at the time of assembly of the internal combustion engine 100, when the vicinity of the another end side (Z1 side) of the connected cylinder 10, which is located in the vicinity of a top dead center of the piston, thermally expands during the operation of the internal combustion engine 100, a gap at each of the first interface and the second interface may be eliminated in some cases. In this case, the another end side (Z1 side) of the connected cylinder 10 is pressed by the fixing member 80. Consequently, the cylinder bore 20 is liable to be deformed. However, when a dimensional design is made so that a minimum gap at each of the first interface and the second interface is increased to prevent the deformation described above, it becomes difficult to firmly fix the another end side (Z1 side) of the connected cylinder 10.

[0143] In order to suppress the above-mentioned dilemma, the sectional shape of the fixing member 80 may be, for example, an inverted trapezoidal. In this case, the interface between the fixing member 80 and the connected cylinder 10 is inclined so as to be closer to the center line C of the cylinder bore 20 in a direction from the one end side (Z2 side) toward the another end side (Z1 side) of the cylinder block main body 60, and the interface between the fixing member 80 and the cylinder block main body 60 is inclined so as to be separated from the center line C of the cylinder bore 20 in the direction from the one end side (Z2 side) toward the another end side (Z1 side) of the cylinder block main body 60. Thus, when the vicinity of the another end side (Z1 side) of the connected cylinder 10, which is located in the vicinity of the top dead center of the piston, thermally expands during the operation of the internal combustion engine 100, a pressing force applied from the connected cylinder 10 side to the fixing member 80 side is likely to be eased by sliding of the fixing member 80 toward the another end side (Z1 side) .

[0144] Further, a material that forms the fixing member 80 is not particularly limited. For example, various metal materials such as an aluminum alloy, a magnesium alloy, an iron alloy such as steel, a resin material, an organic-inorganic composite material, or ceramics such as alumina (aluminum oxide) may be used.

[0145] As the connected cylinder 10 to be used for the method of manufacturing an internal combustion engine according to this embodiment, a shape and a structure of the first connected cylinder 10A are not particularly limited as long as the first connected cylinder 10A includes the two or more cylinder liners 40 and the connecting portion 42 configured to connect the two or more cylinder liners 40 to each other, and a shape and a structure of the second connected cylinder 10B are not particularly limited as long as the second connected cylinder 10B includes the connected cylinder main body portion 50 having the two or more cylinder bores 20 and the coatings 52 configured to cover the inner peripheral surfaces 50B of the connected cylinder main body portion 50 in which the cylinder bores 20 are formed. Similarly, a shape and a structure of the cylinder block main body 60 are not particularly limited as long as the cylinder block main body 60 has one end side (Z2 side) where the crankcase 62 is formed and another end side (Z1 side) where the cylinder head is attachable, and the hollow portion 64 passing through the cylinder block main body 60 from the one end side to the another end side.

[0146] Meanwhile, it is preferred that the connected cylinder 10 and the cylinder block main body 60 achieve all of excellent maintainability, excellent recycling efficiency, and a high degree of freedom in design of the internal combustion engine 100 to be manufactured through use of the connected cylinder 10 and the cylinder blockmainbody 60, and have easilymanufacturable shape and structure. However, the connected cylinder 10 and the cylinder block main body 60 are combined for use in manufacture of the internal combustion engine 100. Therefore, even when the shape and the structure of the connected cylinder 10 are determined in consideration only of the manufacturability of the connected cylinder 10, the shape and the structure of the cylinder block main body 60 to be used in combination with the connected cylinder 10 are complicated to reduce the manufacturability of the cylinder block main body 60, and further, to reduce the manufacturability of the internal combustion engine 100 in some cases. The same applies to a case in which the shape and the structure of the cylinder block main body 60 are determined in consideration only of the manufacturability of the cylinder block main body 60. Therefore, in consideration of the above-mentioned points, the inventors of the present invention have found that shapes and structures described below are suitable as the shape and the structure of the connected cylinder 10 and the shape and the structure of the cylinder block main body 60 to be used in combination therewith.

[0147] First, the first connected cylinder 10A includes the two or more cylinder liners 40 and the connecting portion42 configured to connect the two or more cylinder liners 40 to each other, and has the connected ring-like outer peripheral shape having the ring-like portions each with the diameter obtained by increasing the bore diameter Db of each of the cylinder liners 40, as exemplified in FIG. 9 for illustrating a sectional structure (YZ sectional structure) of the first connected cylinder 10A illustrated in FIG. 1 and FIG. 3, which is taken along the line IX-IX. Further, it is preferred that an outer diameter D1 of an outer peripheral surface (first region 10S1) from a vicinity of the cylinder head side to a vicinity of a central portion in the direction of the center line C of each of the cylinder liners 40, which is based on the center line C of each of the cylinder liners 40 as a reference, be larger than an outer diameter D2 of an outer peripheral surface (second region 10S2) in a vicinity of the crankcase side, which is based on the center line C of each of the cylinder liners 40 as a reference, and a level difference 14, which is parallel to an outer peripheral direction and is continuous, be formed between the first region 10S1 and the second region 10S2.

[0148] The second connected cylinder 10B includes the connected cylinder main body portion 50 having the two or more cylinder bores 20 and the coatings 52 configured to cover the inner peripheral surfaces 50B of the connected cylinder main body portion 50 in which the cylinder bores 20 are formed, and has the connected ring-like outer peripheral shape having the ring-like portions each with the diameter obtained by increasing the bore diameter Db of each of the cylinder bores 20, as exemplified in FIG. 10 for illustrating a sectional structure (YZ sectional structure) of second connected cylinder 10B illustrated in FIG. 5, which is taken along the line X-X. Further, it is preferred that an outer diameter D1 of an outer peripheral surface (first region 10S1) from avicinity of the cylinder head side to a vicinity of a central portion in the direction of the center line C of each of the cylinder bores 20, which is based on the center line C of each of the cylinder bores 20 as a reference, be larger than an outer diameter D2 of an outer peripheral surface (second region 10S2) in a vicinity of the crankcase side, which is based on the center line C of each of the cylinder bores 20 as a reference, and a level difference 14, which is parallel to an outer peripheral direction and is continuous, be formed between the first region 10S1 and the second region 10S2. The outer peripheral shape of the second connected cylinder 10B illustrated in FIG. 10 is similar to the outer peripheral shape of the first connected cylinder 10A illustrated in FIG. 1.

[0149] For the cylinder block main body 60, it is preferred that an opening shape of the hollow portion 64 be a connected ring shape corresponding to the outer peripheral shape of the connected cylinder 10 exemplified in FIG. 1, FIG. 9, and FIG. 10. More specifically, as exemplified in FIG. 6 and FIG. 8, it is preferred that a relationship of W1>W2>W3 is satisfied in the case that; the inner peripheral surface 64S of the hollow portion 64 has a first level difference 68A, which is continuous in the circumferential direction, and a second level difference 68B, which is continuous in the circumferential direction and is formed so as to be closer to the one end side (crankcase side) than the first level difference 68A; an opening width W1 of a portion of the hollow portion 64 having an inner peripheral surface 64S1, which is located on the another end side (cylinder head side) of the first level difference 68A; an opening width W2 of a portion of the hollow portion 64 having an inner peripheral surface 64S2, which is located on the one end side (crankcase side) of the second level difference 68A and on the another end side (cylinder head side) of the second level difference 68B; and an opening width W3 of a portion of the hollow portion 64 having an inner peripheral surface 64S3, which is located on the one end side (crankcase side) of the second level difference 68B. The opening widths W1, W2, and W3 are opening widths each in a suitable direction, regardless of whether the opening width is an opening width of an opening shape of the hollow portion 64 in a transverse direction (Y direction) or an opening width of the opening shape of the hollow portion 64 in a longitudinal direction (X direction) . Specifically, it is preferred that the relationship of W1>W2>W3 be satisfied regardless of whether the opening width is that in the transverse direction (Y direction) or that in the longitudinal direction (X direction). Opening widths W1sm, W2sm, and W3sm illustrated in FIG. 8 represent maximum opening widths in the transverse direction (Y direction) of the opening shape of the hollow portion 64 and correspond to the opening widths W1, W2, and W3, respectively. The opening widths W2sm and W3sm are equal to the outer diameters D1 and D2 of the connected cylinder 10, respectively.

[0150] When the connected cylinder 10 having the level difference 14 formed on the outer peripheral surface 10S is fitted to the hollow portion 64 of the cylinder block main body 60 having the inner peripheral surface 64S on which the first level difference 68A and the second level difference 68B are formed, the fitting is achieved so that the second level difference 68B formed on the inner peripheral surface 64S of the cylinder block main body 60 and the level difference 14 formed on the outer peripheral surface 10S of the connected cylinder 10 match each other in the direction of the center line C. At the same time, on the side closer to the crankcase with respect to the first level difference 68A, the inner peripheral surface 64S2 of the cylinder block main body 60 and the outer peripheral surface 10S (specifically, the first region 10S1) of the connected cylinder 10 are directly held in close contact with each other or held in close contact with each other through the sealing member, and the inner peripheral surface 64S3 of the cylinder block main body 60 and the outer peripheral surface 10S (specifically, the second region 10S2) of the connected cylinder 10 are directly held in close contact with each other or held in close contact with each other through the sealing member. Specifically, on the outer peripheral surface 10S of the connected cylinder 10, a portion of the first region 10S1, which is located on a side closer to the second region 10S2, and the second region 10S2 form a fitting portion corresponding to the fitting portion 64J of the cylinder block main body 60. Therefore, on the cylinder head side with respect to the first level difference 68A, the coolant in the coolant jacket 70 that is formed between the inner peripheral surface 64S1 of the cylinder block main body 60 and the outer peripheral surface 10S (specifically, the first region 10S1) of the connected cylinder 10 can be prevented from leaking toward the crankcase 62.

[0151] Further, a capacity of the coolant jacket 70 and a formation position of the coolant jacket 70 in the direction of the center line C, which affect cooling characteristics inside the cylinder bores 20 and in the vicinity of the cylinder bores 20, can be easily adjusted by selecting, for example, when focusing on the cylinder block main body 60 side, (1) a value of the maximum opening width W1sm and (2) a formation position of the first level difference 68A in the direction of the center line C. The changes in size and shape of the cylinder block main body 60, which are described above in the items (1) and (2), are extremely easy even when the cylinder block main body 60 is manufactured by the casting or the resin molding. The reason is as follows. Even when the cylinder block main body 60 is manufactured by the casting or the resin molding, with which a defective failure due to the volume contraction is liable to occur, the cylinder block main body 60 has an extremely smaller volume capacity than that of the related-art cylinder block that is formed by cast-in of the cylinder liners, and thus the defective failure described above is less liable to occur.

[0152] The level difference 14 formed at a position corresponding to the second level difference 68B formed on the cylinder block main body 60 can be formed at an appropriate position on the outer peripheral surface 10S in the direction of the center line C. When an end surface of the connected cylinder 10 in the direction of the center line C, which is located on the side closer to the crankcase 62, is defined as a reference position (position 0) and the end surface thereof, which is located on the side closer to the cylinder head, is defined as a position L, it is preferred that the level difference 14 be formed to fall within a range larger than 0 and equal to or smaller than 1/2L, more preferably, within a range equal to or larger than 1/6L and equal to or smaller than 3/7L, further preferably, within a range equal to or larger than 1/6L and equal to or smaller than 1/3L. When the level difference 14 is formed at the position that is larger than 1/2L, the first level difference 68A that is formed on the cylinder block main body 60 is required to be formed at a position closer to the cylinder head. Therefore, in the direction of the center line C, a range in which the first level difference 68A is formed is further reduced. As a result, a margin for increasing or reducing the depth D of the coolant jacket 70 by a design change in accordance with the requirement specifications of the internal combustion engine 100 is reduced.

[0153] It is preferred that the outer peripheral shape of the connected cylinder 10 basically be a simple shape having the level difference 14 that divides the outer peripheral surface 10S into the first region 10S1 and the second region 10S2. The groove 12 to which the fixing member 80 is to be fitted or the groove to which the sealing member is to be mounted may be formed as needed.

[0154] Meanwhile, the projecting portion that projects from the outer peripheral surface 10S can be formed on the outer peripheral surface 10S of the connected cylinder 10 when needed, or the projecting portion is not required to be formed on any of the first region 10S1 and the second region 10S2 of the outer peripheral surface 10S of the connected cylinder 10.

[0155] When the projecting portion is not formed on the outer peripheral surface 10S, the following advantages are given. Specifically, when the projecting portion such as a flange is formed on the outer peripheral surface 10S, the projecting portion is liable to be broken when the connected cylinder 10 is carelessly hit against another member while the connected cylinder 10 is being handled or stored. When the projecting portion is not formed on the outer peripheral surface 10S, however, the damage described above can be prevented.

[0156] In addition, in a case in which the connecting portion 42 of the first connected cylinder 10A or the connected cylinder main body portion 50 of the second connected cylinder 10B is manufactured by the casting, when the projecting portion is formed on the outer peripheral surface 10S, a shape of the die becomes slightly complicated. In addition, the manufacturability is reduced by some degree. Further, when the projecting portion is formed on the first region 10S1, it becomes more difficult to redesign the capacity of the coolant jacket 70 and the formation position of the coolant jacket 70 in the direction of the center line C by appropriately redetermining (1) the value of the maximum opening width W1sm and (2) the first level difference 68A in the direction of the center line C of the cylinder block main body 60. When the projecting portion is not formed on the outer peripheral surface 10S, however, the above-mentioned problems can be prevented.

[0157] Meanwhile, although the above-mentioned advantages are lost, cooling control for the internal combustion engine 100 can be more precisely performed by forming the projecting portion on the first region 10S1 of the outer peripheral surface 10S. In this case, as in the case of a first connected cylinder 10A2 (10A, 10) exemplified in FIG. 11, it is preferred that the flange portion 16A (16) that partitions the first region 10S1 into a region on the cylinder head side (Z1-direction side) and a region on the crankcase side (Z2-direction side) be formed on the first region 10S1. In the example illustrated in FIG. 11, the flange portion 16A is formed continuously along the outer peripheral direction and has a connected ring shape that is arranged at a position in the direction of the center line C of the cylinder liner 40 so that the position is the same at any position in the outer peripheral direction. The first connected cylinder 10A2 illustrated in FIG. 11 is a member having the same structure as that of the first connected cylinder 10A1 illustrated in FIG. 9 except that the flange portion 16A is formed on the first region 10S1. The flange portion 16A similar to that illustrated in FIG. 11 can also be formed on the first region 10S1 of the second connected cylinder 10B (10) illustrated in FIG. 10.

[0158] In the internal combustion engine 100 that uses the connected cylinder 10 having the flange portion 16A that partitions the first region 10S1 into the region on the cylinder head side (Z1-direction side) and the region on the crankcase side (Z2-direction side), the coolant jacket 70 has a structure divided by the flange portion 16A in the direction of the center line C of the cylinder liner 40 or the cylinder bore 20. FIG. 12 and FIG. 13 are schematic sectional views each for illustrating an example of the internal combustion engine 100 including the connected cylinder 10 having the flange portion 16A formed on the first region 10S1. An internal combustion engine 100B (100) illustrated in FIG. 12 has the same structure as that of the internal combustion engine 100A illustrated in FIG. 8 except that the first connected cylinder 10A1 illustrated in FIG. 8 is replaced by the first connected cylinder 10A2 having the flange portion 16A illustrated in FIG. 11. An internal combustion engine 100C (100) illustrated in FIG. 13 has the same structure as that of the internal combustion engine 100A illustrated in FIG. 8 except that (i) the first connected cylinder 10A1 illustrated in FIG. 8 is replaced by the first connected cylinder 10A2 having the flange portion 16A illustrated in FIG. 11, and (ii) the cylinder block main body 60A illustrated in FIG. 8 is replaced by a cylinder block main body 60B having a structure in which a third level difference 68C being continuous in the circumferential direction is formed on the inner peripheral surface 64S1 of the cylinder block main body 60A.

[0159] The third level difference 68C is formed at a position corresponding to a side surface of the flange portion 16A, which is located on the crankcase side (Z2-direction side) . Based on the third level difference 68C as a boundary line, the internal peripheral surface 64S1 is partitioned into two regions, that is, a cylinder head-side region 64S1A, which is located on the cylinder head side (Z1-direction side) with respect to the third level difference 68C, and a crankcase-side region 64S1B, which is located on the crankcase side (Z2-direction side) with respect to the third level difference 68C. The crankcase-side region 64S1B is positioned on an inner peripheral side relative to the cylinder head-side region 64S1A. In the Y direction, the cylinder head-side region 64S1A illustrated in FIG. 13 is formed at a position so as to be flush with the inner peripheral surface 64S1 of the cylinder block main body 60A illustrated in FIG. 12. However, the cylinder head-side region 64S1A illustrated in FIG. 13 is not required to be formed at the position so as to be flush with the inner peripheral surface 64S1 of the cylinder block main body 60A illustrated in FIG. 12 as long as the cylinder head-side region 64S1A is positioned on an outer peripheral side relative to the crankcase-side region 64S1B.

[0160] In the internal combustion engine 100B illustrated in FIG. 12 and the internal combustion engine 100C illustrated in FIG. 13, the coolant jacket 70, which is formed between the outer peripheral surface 10S (specifically, the first region 10S1) of the first connected cylinder 10A and the inner peripheral surface 64S1 of the hollow portion 64 of the cylinder block main body 60A, 60B, is divided by the flange portion 16A into a cylinder head-side portion (a cylinder head-side coolant jacket 70A) and a crankcase-side portion (a crankcase-side coolant jacket 70B). Therefore, the internal combustion engine 100B illustrated in FIG. 12 and the internal combustion engine 100C illustrated in FIG. 13 can control a flow velocity, a flow rate, and a water temperature of the coolant flowing in the coolant jacket 70 individually for the cylinder head-side coolant jacket 70A and the crankcase-side coolant jacket 70B in comparison to the internal combustion engine 100A illustrated in FIG. 8. Therefore, in the internal combustion engines 100B and 100C, it is extremely easy to perform temperature control individually for a portion closer to the cylinder head and a portion closer to the crankcase, which are included in a portion of the cylinder bores 20 surrounded by the coolant jacket 70. When the characteristics described above are used, various advantages exemplified in the following items (a) to (c) can be easily achieved.

(a) A cylindricity of each of the cylinder bores 20 during an operation of the internal combustion engine 100B, 100C is improved by controlling a temperature of the portion closer to the cylinder head and a temperature of the portion closer to the crankcase, which are included in the portion of the cylinder bores 20 surrounded by the coolant jacket 70. For example, the control can be performed so that the temperature of the portion of the cylinder bores 20, which is closer to the cylinder head, is reduced and the temperature of the portion of the cylinder bores 20, which is closer to the crankcase, is increased in comparison to temperatures before the coolant jacket 70 is divided by the flange portion 16A. In this case, with the reduction in temperature of the portion of the cylinder bores

20, which is closer to the cylinder head, it becomes easy to increase an output and further advance ignition. Further, with the increase in temperature of the portion of the cylinder bores 20, which is closer to the crankcase, it becomes easy to reduce friction and improve warm-up performance. In addition, the cylindricity of each of the cylinder bores 20 is improved. Thus, along with the improvement of the cylindricity, it becomes easy to reduce a blow-by gas amount and a lubricant-oil consumption amount.

(b) A temperature of an inner wall surface (sliding surface) of the cylinder bore 20, which is closer to the cylinder head, is decreased by improving cooling efficiency of the portion closer to the cylinder head relative to that of the portion closer to the crankcase, which are included in the portion of the cylinder bores 20 surrounded by the coolant jacket 70. In this manner, anti-knocking capability is improved to improve the fuel efficiency.

(c) A flow velocity, a flow rate, and a water temperature of the coolant in the cylinder head-side coolant jacket 70A and a flow velocity, a flow rate, and a water temperature of the coolant in the crankcase-side coolant jacket 70B are individually set so that optimal output, fuel efficiency, and other advantages are obtained in accordance with operating conditions of the internal combustion engine 100B, 100C.

[0161] In the internal combustion engine 100B illustrated in FIG. 12, a top surface of the flange portion 16A is held in contact with the inner peripheral surface 64S1 of the cylinder block main body 60A. In the internal combustion engine 100C illustrated in FIG. 13, the top surface of the flange portion 16A is held in contact with the cylinder head-side region 64S1A of the inner peripheral surface 64S1 of the cylinder block main body 60A, and a crankcase-side (Z2-direction side) side surface of the flange portion 16A, which is located on the top surface side, is held in contact with a level-difference surface portion of the third level difference 68C. In this case, it is preferred that a sealing member such as an O-ring be provided at an interface between the top surface of the flange portion 16A and the inner peripheral surface 64S1 to completely seal the interface between the flange portion 16A and the inner peripheral surface 64S1. The O-ring may be mounted in, for example, a groove that is formed in the top surface of the flange portion 16A along the circumferential direction so as to be used. In the case of the internal combustion engine 100C illustrated in FIG. 13, the O-ring may be mounted in a groove that is formed in the level-difference surface portion of the third level difference 68C along the circumferential direction so as to be used.

[0162] The sealing member may be omitted or a slight gap may be formed between the top surface of the flange portion 16A and the inner peripheral surface 64S1 as long as controllability for controlling the flow velocity, the flow rate, and the water temperature of the coolant individually for the cylinder head-side coolant jacket 70A and the crankcase-side coolant jacket 70B is not greatly impaired. A flow passage, which penetrates in the direction of the center line C to connect the cylinder head-side coolant jacket 70A and the crankcase-side coolant jacket 70B to each other, may be formed in a portion of the flange portion 16A in the circumferential direction as needed.

[0163] The flange portion 16Acan be formed at a freely-selected position on the first region 10S1 in the direction of the center line C as long as the coolant jacket 70 can be divided into the cylinder head-side coolant jacket 70A and the crankcase-side coolant jacket 70B. When a cylinder head-side end of the first region 10S1 in the direction of the center line C is defined as a reference position 0 and a total length of the first region 10S1 in the direction of the center line C is defined as L1, it is preferred that the flange portion 16A be formed to fall within a range of from about 0.2×L1 to about 0.5×L1. Similarly, when a cylinder head-side end of the connected cylinder 10 in the direction of the center line C is defined as a reference position 0 and a total length of the connected cylinder 10 in the direction of the center line C is defined as L, it is preferred that the flange portion 16A be formed to fall within a range of from about 0.14×L to about 0.37×L.

[0164] Further, the flange portion 16 formed on the outer peripheral surface 10S maybe formed continuously along the direction of the center lines C of the cylinder liners 40 or the cylinder bores 20. FIG. 15 is a schematic sectional view for illustrating another modification example of the first connected cylinder illustrated in FIG. 1. A first connected cylinder 10A3 (10A, 10) illustrated in FIG. 15 has flange portions 16B (16), which are formed on the outer peripheral surface 10S so as to be located on both end sides in the direction of arrangement of the cylinder bores 20 and continuous along the direction of the center lines C. In the internal combustion engine 100 using the first connected cylinder 10A3 illustrated in FIG. 15, the coolant jacket 70 is divided into a portion on the one side (Y1 side) of the plane (ZX plane) containing the center line C of each of the cylinder liners 40 or each of the cylinder bores 20 and a portion on the another side (Y2 side) . In the example illustrated in FIG. 15, the flange portions 16B are formed on the outer peripheral surface 10S so as to be located on both end sides in the direction of arrangement of the cylinder bores 20. However, the flange portions 16B may be formed at positions other than those described above.

[0165] In the example illustrated in FIG. 15, each of the flange portions 16B is formed on both of the first region 10S1 and the second region 10S2 of the outer peripheral surface 10S. Thus, guide grooves corresponding to the flange portions 16B are formed at least in the inner peripheral surfaces 64S2 and 64S3 of the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60, which is to be used in combination with the first connected cylinder 10A3 illustrated in FIG. 15. Further, guide grooves corresponding to the flange portions 16B may be formed even in the inner peripheral surface 64S1 in addition to the inner peripheral surfaces 64S2 and 64S3 in accordance with a height of each of the flange portions 16B. Specifically, the guide grooves corresponding to the flange portions 16B are formed in the inner peripheral surface 64S so as to be located on both end sides in a longitudinal direction (X direction) of the opening portion of the hollow portion 64 and continuous at least partially or entirely from the one end side (Z2 side) to the another end side (Z1 side) of the hollow portion 64. Thus, when the flange portions 16B of the first connected cylinder 10A3 are fitted into the guide grooves, the first connected cylinder 10A3 is more stably fixed to the cylinder block main body 60 having the inner peripheral surface 64S with the guide grooves formed therein.

[0166] In the example illustrated in FIG. 15, the flange portions 16B are formed on the outer peripheral surface 10S so as to be continuous from the one end side (Z2 side) to the another end side (Z1 side) of the first connected cylinder 10A3. However, when the flange portions 16B are formed for more stable fixation of the first connected cylinder 10A3 to the cylinder block main body 60 as a main purpose, the flange portions 16B are only required to be formed on the outer peripheral surface 10S to extend from a position closer to the another end side (Z1 side) with respect to the level difference 14 to the one end side (Z2 side) so as to correspond to the guide grooves formed in the inner peripheral surfaces 64S2 and 64S3 of the inner peripheral surface 64S of the hollow portion 64. In FIG. 16, there is illustrated a first connected cylinder 10A4 (10A, 10) having the outer peripheral surface 10S with the flange portions 16B formed thereon as described above.

[0167] When the flange portions 16B are formed for division of the coolant jacket 70 as a main purpose, the flange portions 16B are only required to be formed on the outer peripheral surface 10S to extend from the another end side (Z1 side) to a position closer to the another end side (Z1 side) with respect to the level difference 14 so as to correspond to the inner peripheral surface 64S1 of the hollow portion 64. In FIG. 17, there is illustrated a first connected cylinder 10A5 (10A, 10) having the outer peripheral surface 10S with the flange portions 16B formed thereon as described above.

[0168] The internal combustion engine 100 that is assembled with the first connected cylinder 10A3, 10A4, 10A5, which has the outer peripheral surface 10S with the flange portions 16B formed continuously along the direction of the center lines C of the cylinder liners 40 or the cylinder bores 20, and the cylinder block main body 60 can be used for any types of engines such as an inline engine, a V-type engine, or a horizontally-opposed engine.

[0169] It is particularly preferred that the internal combustion engine 100 using the first connected cylinder 10A3 exemplified in FIG. 15 or the first connected cylinder 10A4 exemplified in FIG. 16 be a horizontally-opposed engine. In this case, in the horizontally-opposed engine, even when gravity acts on the first connected cylinder 10A4 in a direction substantially orthogonal to the center lines C of the cylinder bores 20, inclination of the first connected cylinder 10A4 with respect to a horizontal plane can be reliably suppressed. Thus, when the internal combustion engine 100 is assembled under a state in which the cylinder block main body 60 having the inner peripheral surface 64S with the guide grooves formed therein is placed sideways (state in which the Z direction substantially matches with a horizontal direction), positioning of the first connected cylinder 10A4 with respect to the cylinder block main body 60 is easy.

[0170] In FIG. 18, there is illustrated an example of the cylinder block main body to be used in combination with the first connected cylinder 10A3 illustrated in FIG. 15. A cylinder block main body 60C (60) illustrated in FIG. 18 is a modification example of the cylinder block main body 60A illustrated in FIG. 6, and is a member having the same dimensions and shape as those of the cylinder block main body 60A except that guide grooves 69 are further formed in the cylinder block main body 60A. As illustrated in FIG. 18, the guide grooves 69 are formed in the inner peripheral surface 64S so as to be located on both end sides in a longitudinal direction (X direction) of an opening portion 64X of the hollow portion 64. In this case, the guide grooves 69 are formed in all of the inner peripheral surface 64S1, the inner peripheral surface 64S2, and the inner peripheral surface 64S3 so as to correspond to the flange portions 16B illustrated in FIG. 15. The guide grooves 69 may be omitted from the inner peripheral surface 64S1 in accordance with the height of each of the flange portions 16B. Further, even when the first connected cylinder 10A4 illustrated in FIG. 16 is used, the guide grooves 69 are not required to be formed in the inner peripheral surface 64S1.

[0171] Further, a shape and a position of formation of the flange portion 16 are not limited to those of the examples illustrated in FIG. 11 to FIG. 13 and FIG. 15 to FIG. 17. For example, the flange portion 16 may be a combination of the flange portion 16A formed continuously in the outer peripheral direction as exemplified in FIG. 11 to FIG. 13 and the flange portions 16B formed continuously in the direction parallel to the center lines C as exemplified in FIG. 15 to FIG. 17.

[0172] For example, it is supposed that the first region 10S1 of the connected cylinder 10 is divided into two by a plane (XZ plane) containing the center lines C of the cylinder liners 40 or the cylinder bores 20 as a divisional boundary plane. In this case, the flange portion 16A having a connected semi-ring shape that is continuous so as to be parallel to the outer peripheral direction can be formed at a position relatively closer to the crankcase in one-side portion (Y1-direction side portion) of the first region 10S1 that has been divided into two, whereas the flange portion 16A having a connected semi-ring shape that is continuous so as to be parallel to the outer peripheral direction can be formed at a position relatively closer to the cylinder head in another-side portion (Y2-direction side portion) of the first region 10S1 that has been divided into two. Each end of the one flange portion 16A having the connected semi-ring shape and each end of the another flange portion 16A having the connected semi-ring shape are connected through the flange portion 16B formed so that the ends thereof are continuous in a direction parallel to the center line C. By adopting the configuration described above, a ratio of a depth of the cylinder head-side coolant jacket 70A and a depth of the crankcase-side coolant jacket 70B can be set so as to be different for the one side and the another side of the divisional boundary plane. The structure described above is effective in a case in which, for example, asymmetric cooling control is desired to be performed for the one side and the another side of the divisional boundary plane.

[0173] Further, the flange portion 16 may include, in addition to a first portion (flange portion 16A) that partitions the first region 10S1 into the cylinder head-side (Z1-direction side) region and the crankcase-side (Z2-direction side) region, a second portion (flange portion 16B) that partitions a portion of the first region 10S1, which forms a side wall surface of the coolant jacket 70, in the outer peripheral direction. In the internal combustion engine 100 including the connected cylinder 10 having the flange portion 16 described above, the coolant jacket 70 can be partitioned by the first portion in the direction of the center line C of the cylinder liner 40 or the cylinder bore 20. In addition, the coolant jacket 70 can also be partitioned or divided by the second portion in the outer peripheral direction. Thus, it becomes easy to perform more precise cooling control not only in the direction of the center line C but also in the outer peripheral direction.

[0174] As a specific example, there can be exemplified the connected cylinder 10 having the flange portion 16 formed on the first region 10S1, the flange portion 16 having the first portion (flange portion 16A), which is formed continuously along the outer peripheral direction and forms such a connected ring shape that the position of arrangement thereof in the direction of the center line C is the same at any position in the outer peripheral direction, and two linear second portions (flange portion 16B), which are formed along a portion at which the divisional boundary plane and the first region 10S1 intersect with each other, and the internal combustion engine 100 using the same. In this case, the coolant jacket 70 is divided by the first portion into the cylinder head-side coolant jacket 70A and the crankcase-side coolant jacket 70B. Further, by the second portions, the cylinder head-side coolant jacket 70A is divided into the portion on the one side (Y1-direction side) of the divisional boundary plane and the portion on the another side (Y2-direction side), and the crankcase-side coolant jacket 70B is divided into the portion on the one side (Y1-direction side) of the divisional boundary plane and the portion on the another side (Y2-direction side) . Specifically, the coolant jacket 70 is divided into four.

[0175] The internal combustion engine 100 having the structure in which the flange portions and the guide grooves are fitted together to fix the connected cylinder 10 to the cylinder block main body 60 as described with the specific examples illustrated in FIG. 15, FIG. 16, and FIG. 18 may include a combination of the connected cylinder 10 and the cylinder block main body 60, which have at least the structures described in the following item (1) or (2).

(1) The internal combustion engine 100 includes the connected cylinder 10 having the outer peripheral surface 10S on which the flange portions 16B (fixing flange portions) are formed along the direction parallel to the center line C of each of the cylinder bores 20 formed in the connected cylinder 10 and the cylinder block main body 60 having the guide grooves 69 formed in the inner peripheral surface 64S of the hollow portion 64, which are to be fitted to the flange portions 16B (fixing flange portions).
(2) The internal combustion engine 100 includes the cylinder block main body 60 having the flange portions (fixing flange portions) formed on the inner peripheral surface 64S of the hollow portion 64 along a direction parallel to a penetrating direction (Z direction) of the hollow portion 64 and the connected cylinder 10 having the guide grooves formed in the outer peripheral surface 10S of the connected cylinder 10, which are to be fitted to the flange portions (fixing flange portions) (formed on the cylinder block main body 60) .

[0176] In this case, it is preferred that the internal combustion engines 100 described in the items (1) and (2) have the structures described below, respectively.

[0177] Specifically, in the internal combustion engine 100 described above in the item (1), it is preferred that the flange portions 16B (fixing flange portions) be formed on the outer peripheral surface 10S of the connected cylinder 10 so as to be located on both end sides in the direction of arrangement of the cylinder bores 20 (X direction) formed in the connected cylinder 10 and the guide grooves 69 be formed in the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60 so as to be located on both end sides in the longitudinal direction (X direction) of the opening portion 64X of the hollow portion 64. Further, in the internal combustion engine 100 described above in the item (2), it is preferred that the flange portions (fixing flange portions) be formed on the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60 so as to be located on both end sides in the longitudinal direction (X direction) of the opening portion 64X of the hollow portion 64 and the guide grooves be formed in the outer peripheral surface 10S of the connected cylinder 10 so as to be located on both end sides in the direction of arrangement of the cylinder bores 20 (X direction) formed in the connected cylinder 10.

[0178] The structures as described above in each of which the fixing flange portions and the guide grooves are fitted together on both end sides in the X direction are particularly suitable when the internal combustion engine 100 is a horizontally-opposed engine. In this case, the inclination of the connected cylinder 10 in the internal combustion engine 100 can be suppressed, and the positioning of the connected cylinder 10 with respect to the cylinder block main body 60 at the time of assembly can be facilitated.

[0179] In the internal combustion engines 100 described above in the items (1) and (2), the coolant jacket may be provided at any of the following positions (i) to (iii). It is particularly preferred that the coolant jacket be provided at the position (ii) . When the coolant jacket 70 that forms a large space between the outer peripheral surface 10S of the connected cylinder 10 and the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60 is provided, support and fixation of the connected cylinder 100 in the internal combustion engine 100 are liable to be unstable in comparison to a case in which the coolant jacket is provided at the position (i) or (iii) . However, in the internal combustion engines 100 described in the above-mentioned items (1) and (2), each having the structure in which the fixing flange portions and the guide grooves are fitted together, the above-mentioned problem can be suppressed.

[0180] Specifically, the coolant jacket is provided:

(i) in the connected cylinder 10 (inside the outer peripheral surface 10S of the connected cylinder 10),
(ii) between the outer peripheral surface 10S of the connected cylinder 10 and the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60, or
(iii) in the cylinder block main body 60 (on an outer peripheral side of the inner peripheral surface 64S of the hollow portion 64) .

[0181] In the internal combustion engine 100 including the coolant jacket 70 provided at the position (ii), a flange portion (dividing flange portion) that divides the coolant jacket 70 into two or more portions is only required to be formed at least on any surface selected from (a) the outer peripheral surface 10S of the connected cylinder 10 and (b) the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60.

[0182] In this case, as a specific example in which the dividing flange portion is formed on (a) the outer peripheral surface 10S of the connected cylinder 10, there are given the internal combustion engine 100B illustrated in FIG. 12, the internal combustion engine 100C illustrated in FIG. 13, and the internal combustion engine 100 in which the first connected cylinder 10A3 illustrated in FIG. 15 and the cylinder block main body 60C illustrated in FIG. 18 are combined. In the internal combustion engine 100B illustrated in FIG. 12 and the internal combustion engine 100C illustrated in FIG. 13, the coolant jacket 70 is divided by the flange portion 16A (dividing flange portion) into two portions (the cylinder head-side coolant jacket 70A and the crankcase-side coolant jacket 70B).

[0183] Further, in the internal combustion engine 100 in which the first connected cylinder 10A3 illustrated in FIG. 15 and the cylinder block main body 60C illustrated in FIG. 18 are combined, the coolant jacket 70 is divided by the flange portions 16B (dividing flange portions) into two portions (the portion on the one side (Y1 side) with respect to the plane containing the plurality of center lines C and the portion on the another side (Y2 side)). The flange portions 16B in the internal combustion engine 100 in which the first connected cylinder 10A3 illustrated in FIG. 15 and the cylinder block main body 60C illustrated in FIG. 18 are combined are used as the fixing flange portions. However, the flange portions 16B also have a function of the dividing flange portions. As described above, the fixing flange portions may have a function of the dividing flange portions.

[0184] Meanwhile, as a specific example in which the dividing flange portions are formed on the inner peripheral surface 64S of the hollow portion 64 of the cylinder block main body 60, there are given the internal combustion engine 100 having a structure that the flange portions (dividing flange portions) in the internal combustion engine 100B illustrated in FIG 12, the internal combustion engine 100C illustrated in FIG. 13, and the internal combustion engine 100 including the combination of the first connected cylinder 10A3 illustrated in FIG. 15 and the cylinder block main body 60C illustrated in FIG. 18, are formed not on the connected cylinder 10 but on the cylinder block main body 60.

[0185] Further, in the first connected cylinder 10A2, 10A3, 10A4, and 10A5 illustrated in FIG. 11 to FIG. 13 and FIG. 15 to FIG. 17, the flange portion 16 is formed integrally with a main body portion of the first connected cylinder 10A2 by casting. However, the flange portion 16 may be formed by mounting and fixing (1) a member having a shape corresponding to the flange portion 16A having the connected ring shape, (2) a member having a shape corresponding to the flange portion 16B having the linear shape extending along the direction parallel to the center lines C, or (3) a member having a shape corresponding to the flange portion 16 having the first portion (flange portion 16A) having the connected semi-ring shape or the connected ring shape described above and the second portion (flange portion 16B) having the linear shape, which are described above, to the connected cylinder 10 without the flange portion 16, as exemplified in FIG. 9 and FIG. 10.

[0186] A type of fitting for the fitting portion at which the flange portion 16 and the cylinder block main body 60 are fitted together is not particularly limited, and may be any type of fitting selected from the clearance fit, the transition fit, and the interference fit. When the deformation of the cylinder bores 20 is desired to be suppressed, the clearance fit or the transition fit is preferred, and the clearance fit is more preferred.

[0187] Further, it is preferred that the flange portion (dividing flange portion) formed on the connected cylinder 10 or the cylinder block main body 60 for purpose of dividing the coolant jacket 70 into two or more portions have no through hole penetrating in a width direction of the flange portion. For example, when the flange portion 16A that is formed continuously along the outer peripheral direction of the connected cylinder 10 or a flange portion that is formed continuously along an inner peripheral direction of the hollow portion 64 of the cylinder block main body 60 in place of the flange portion 16A does not have a through hole, the cylinder head-side coolant jacket 70A and the crankcase-side coolant jacket 70B do not communicate with each other via a through hole. Thus, for example, control of a fluid temperature and a flow rate of the coolant can be more reliably performed separately and independently for the cylinder head-side coolant jacket 70A and the crankcase-side coolant jacket 70B. The "width direction of the flange portion" corresponds to a direction parallel to a surface on which the flange portion is formed and is orthogonal to a longitudinal direction of the flange portion, and corresponds to a length in the Z direction for the flange portion 16A illustrated in FIG. 11 and a length in the outer peripheral direction (or the Y direction) for the flange portions 16B illustrated in FIG. 15.

[0188] Further, when the flange portion (dividing flange portion) has a through hole penetrating in the width direction of the flange portion, it is preferred that the flange portion have a closing member capable of closing the through hole, such as a plug or a lid in addition to the through hole. In this case, it is preferred that the through hole be closed by the closing member such as a plug or a lid when the internal combustion engine 100 is operated. For example, when the flange portion 16A has a through hole in a state of being unclosed when the internal combustion engine 100 is operated, a coolant can move between the cylinder head-side coolant jacket 70A and the crankcase-side coolant jacket 70B through the through hole when, for example, the internal combustion engine 100B exemplified in FIG. 12 is operated. Thus, it becomes difficult to perform more precise cooling control. The above-mentioned points apply even to a case in which the flange portion 16 is formed on the inner peripheral surface 64S1 of the cylinder block main body 60. The through hole may be opened for purpose of, for example, maintenance and repair of the internal combustion engine 100 when the internal combustion engine 100 is not operated.

[0189] In the related-art internal combustion engine having a structure in which the plurality of cylinder liners are cast into the cylinder block, a portion other than the cylinder liners is formed integrally by casting. Therefore, in the related-art internal combustion engine, as in the cases of the internal combustion engine 100B illustrated in FIG. 12 and the internal combustion engine 100C illustrated in FIG. 13, it is impossible to achieve the structure (coolant jacket divided structure) of the coolant jacket 70 divided into the cylinder head-side coolant jacket 70A and the crankcase-side coolant jacket 70B only through the casting process. Further, in order to achieve the coolant jacket divided structure after the casting, work for constructing the coolant jacket divided structure is required to be performed in the coolant jacket having a cylinder head-side opening portion with a small width and a large depth. Thus, the manufacturability is extremely low, and mass production is impossible. In the internal combustion engine 100 according to this embodiment, which uses the connected cylinder 10 having the flange portion 16, however, the coolant jacket divided structure can be extremely easily achieved by combining the connected cylinder 10 having the flange portion 16 manufactured by the casting and the cylinder block main body 60 manufactured by the casting. Thus, mass productivity is extremely excellent.

[0190] The internal combustion engine 100 according to this embodiment is only required to have at least one fitting portion where the connected cylinder 10 and the cylinder block main body 60 are fitted together. The fitting portion in this case corresponds to the one end-side portion (fitting portion 64J) of the hollow portion 64 of the cylinder block main body 60. As exemplified in FIG. 8, FIG. 12, and FIG. 13, however, the internal combustion engine 100 according to this embodiment has two or more fitting portions in the Z direction, specifically, in addition to a first fitting portion (fitting portion 64J) located closest to the one end side (Z2 side), and, for example, a second fitting portion (such as a fitting portion through the fixing member 80 exemplified in FIG. 8, FIG. 12, and FIG. 13) located closest to the another end side (Z1 side), or a third fitting portion (such as a fitting portion between the flange portion 16 and the cylinder block main body 60, which is exemplified in FIG. 12 and FIG. 13) located between the one end side (Z2 side) and the another end side (Z1 side) in the Z direction.

[0191] When the internal combustion engine 100 according to this embodiment has two or more fitting portions in the Z direction as described above, the type of fitting used for the fitting portions may be the same or different. Further, as a combination of suitable types of fitting for the fitting portions, there are given modes exemplified below.

[0192] (Case in which the internal combustion engine 100 has the first fitting portion, the second fitting portion, and the third fitting portion)

- Combination Example A1

[0193] For the first fitting portion to the third fitting portion, the clearance fit is used.

[0194] With the combination described above, it is extremely easy to suppress the deformation of the cylinder bores 20 over the entire region in the Z direction.

• Combination Example A2

[0195] For the first fitting portion, the transition fit is used, and for the second fitting portion and the third fitting portion, the clearance fit is used.

[0196] With the combination described above, it is extremely easy to suppress the deformation of the cylinder bores 20 in the vicinity of a region in which the piston reciprocates, and the connected cylinder 10 can be more stably fixed to the cylinder block main body 60 as compared to the case using the combination example A1.

[0197] (Case in which the internal combustion engine 100 has the first fitting portion and the third fitting portion)

• Combination Example B1

[0198] For the first fitting portion and the third fitting portion, the clearance fit is used.

[0199] With the combination described above, it is extremely easy to suppress the deformation of the cylinder bores 20 over the entire region in the Z direction.

• Combination Example B2

[0200] For the first fitting portion, the transition fit is used, and for the third fitting portion, the clearance fit is used.

[0201] With the combination described above, it is extremely easy to suppress the deformation of the cylinder bores 20 in the region in which the piston reciprocates, and the connected cylinder 10 can be more stably fixed to the cylinder block main body 60 as compared to the case using the combination example B1.

[0202] (Case in which the internal combustion engine 100 has the first fitting portion and the second fitting portion)

• Combination Example C1

[0203] For the first fitting portion and the second fitting portion, the clearance fit is used.

[0204] With the combination described above, it is extremely easy to suppress the deformation of the cylinder bores 20 over the entire region in the Z direction.

• Combination Example C2

[0205] For the first fitting portion, the transition fit is used, and for the second fitting portion, the clearance fit is used.

[0206] With the combination described above, it is extremely easy to suppress the deformation of the cylinder bores 20 in the region in which the piston reciprocates, and the connected cylinder 10 can be more stably fixed to the cylinder block main body 60 as compared to the case using the combination example C1.

[0207] The internal combustion engine 100 according to this embodiment can be used as, for example, a liquid cooled gasoline engine, a liquid cooled diesel engine, or a liquid cooled engine using a fuel other than gasoline or light oil (such as alcohol, a natural gas, or a hydrogen gas). A purpose of use of the internal combustion engine 100 according to this embodiment is not particularly limited, and the internal combustion engine 100 may be used for various purposes of use, for example, for a vehicle such as an automobile, a motorcycle, or a railroad vehicle, a ship, an aircraft, or power generation. The internal combustion engine 100 is particularly suitably used for a vehicle. A displacement of the internal combustion engine 100 according to this embodiment is not particularly limited, and can be appropriately selected in accordance with the purpose of use. In general, the displacement of the internal combustion engine 100 is selected to fall within a range of from 20 cc to 60 L in accordance with the purpose of use. When the internal combustion engine 100 is used for an automobile including a large-size automobile such as a large-size truck or bus, it is preferred that the displacement be selected to fall within a range of, for example, from 50 cc to 30 L. For an automobile other than a large-size automobile such as a large-size truck or bus, it is preferred that the displacement be selected to fall within a range of, for example, from 50 cc to 7 L, and more preferably, from 300 cc to 4 L. Further, for a motorcycle, it is preferred that the displacement be selected to fall within a range of, for example, from 20 cc to 1.5 L, more preferably, from 50 cc to 1.2 L.

[0208] The internal combustion engine 100 according to this embodiment is applicable to, for example, a large-size engine (for example, a large-size diesel engine for, for example, a ship and/or a large-size engine having a displacement exceeding 30 L or 60 L) . However, it is difficult to manufacture the connected cylinder 10 and the cylinder block main body 60 (particularly, the cylinder block main body 60), which correspond to the displacement or a magnitude of the engine size. Thus, it is preferred that the displacement of the internal combustion engine 100 according to this embodiment be 60 L or less, preferably, 30 L or less, and particularly preferably, 10 L or less. For the same reason, the internal combustion engine 100 according to this embodiment is suitably an internal combustion engine except for the large-size engine as described above.

[0209] Further, the connected cylinder 10 according to this embodiment may be combined with a member other than the cylinder block main body 60 to form an internal combustion engine. The structure of the internal combustion engine described above is not particularly limited, and may be of any one of a liquid cooled type or an air cooled type. For example, in a case of a large-size diesel engine for, for example, a ship and/or a large-size engine having a displacement exceeding 30 L or 60 L, the internal combustion engine can be configured to include the connected cylinder 10 and a cover member configured to surround a portion of the outer peripheral surface 10S of the connected cylinder 10, which is on a side closer to the cylinder head. The cover member is fixed to the connected cylinder 10 with use of a plurality of bolts . In this case, a coolant is supplied to a cooling chamber formed between the outer peripheral surface 10S of the connected cylinder 10 and the cover member. In the internal combustion engine having a large engine displacement as described above, even when the cylinder block main body 60, which has large size and volume in accordance with the engine displacement, is desired to be produced by casting, it is difficult to manufacture the cylinder block main body 60 due to a problem such as a blowhole. However, the cover member has a size and a volume which are much smaller than those of the cylinder block main body 60, and thus is easy to manufacture.

Reference Signs List

[0210]

10: connected cylinder
10A, 10A1, 10A2, 10A3, 10A4, 10A5: first connected cylinder
10B: second connected cylinder
10S: outer peripheral surface
10S1: first region (portion of outer peripheral surface 10S)
10S2: second region (portion of outer peripheral surface 10S)
10ES: end surface
12: groove
14: level difference
16, 16A, 16B: flange portion
20: cylinder bore
20B: inner peripheral surface
30, 30A, 30B, 30C: coolant passage
34: opening portion
36: end surface
40: cylinder liner
40A: outer peripheral surface
40B: inner peripheral surface
42: connecting portion
50: connected cylinder main body portion
50B: inner peripheral surface
52: coating
52A: outer peripheral side surface
52B: surface
60, 60A, 60B, 60C: cylinder block main body
62: crankcase
64: hollow portion
64J: fitting portion
64X: opening portion
64S, 64S1, 64S2, 64S3: inner peripheral surface
64S1A: cylinder head-side region (portion of inner peripheral surface 64S1)
64S1B: crankcase-side region (portion of inner peripheral surface 64S1)
66: groove
68A: first level difference
68B: second level difference
68C: third level difference
69: guide grooves
70: coolant jacket
70A: cylinder head-side coolant jacket
70B: crankcase-side coolant jacket
80: (head-side) fixing member
100, 100A, 100B, 100C: internal combustion engine

Claims

1. A method of manufacturing an internal combustion engine, comprising at least a fitting step of fitting a connected cylinder to a hollow portion of a cylinder block main body,
the connected cylinder comprising any one of connected cylinders selected from the group consisting of:

(1) a first connected cylinder including two or more cylinder liners and a connecting portion configured to connect the two or more cylinder liners to each other; and
(2) a second connected cylinder including a connected cylinder main body portion having two or more cylinder bores and a coating configured to cover an inner peripheral surface of the connected cylinder main body portion in which the cylinder bores are formed,

the cylinder block main body having one end side where a crankcase is formed and another end side where a cylinder head is attachable,
the hollow portion passing through the cylinder block main body from the one end side to the another end side.

2. The method of manufacturing an internal combustion engine according to claim 1, wherein the fitting step is carried out through any type of fitting selected from clearance fit, transition fit, and interference fit.

3. The method of manufacturing an internal combustion engine according to claim 1 or 2,
wherein the connected cylinder comprises the first connected cylinder, and
wherein a sliding surface formation step of forming sliding surfaces by finishing inner peripheral surfaces of the cylinder liners is carried out only before the fitting step.

4. The method of manufacturing an internal combustion engine according to any one of claims 1 to 3,
wherein the connected cylinder comprises the first connected cylinder,
wherein, after a coating formation step of forming coatings on inner peripheral surfaces of the cylinder liners is carried out, a sliding surface formation step

of forming sliding surfaces by finishing surfaces of the coatings is carried out, and
wherein the sliding surface formation step is carried out only before the fitting step.

5. The method of manufacturing an internal combustion engine according to claim 1 or 2,
wherein the connected cylinder comprises the second connected cylinder, and
wherein a sliding surface formation step of forming a sliding surface by finishing a surface of the coating configured to cover the inner peripheral surface of the connected cylinder main body portion in which the cylinder bores are formed is carried out only before the fitting step.

6. The method of manufacturing an internal combustion engine according to any one of claims 3 to 5, wherein the fitting step is carried out through any type of fitting selected from clearance fit and transition fit.

7. The method of manufacturing an internal combustion engine according to any one of claims 3 to 5, wherein the fitting step is carried out through clearance fit.

8. The method of manufacturing an internal combustion engine according to any one of claims 3 to 7, wherein the sliding surface formation step is carried out under a state in which the connected cylinder is assembled to a jig that imitates the cylinder block main body and the cylinder head, and at least the connected cylinder is heated.

9. The method of manufacturing an internal combustion engine according to any one of claims 1 to 8, wherein a coolant passage formation step of forming a coolant passage between two adjacent ones of the cylinder bores of the connected cylinder is carried out at least before the fitting step.

10. The method of manufacturing an internal combustion engine according to claim 9,
wherein the coolant passage is formed inside an end surface of the connected cylinder on a side where the cylinder head is arrangeable, and
wherein a sectional shape of the coolant passage, which is taken along a plane being parallel to a center line of each of the cylinder bores formed in the connected cylinder, is a slit-like shape.

11. An internal combustion engine comprising at least:

a connected cylinder selected from the group consisting of:

(1) a first connected cylinder including two or more cylinder liners and a connecting portion configured to connect the two or more cylinder liners to each other; and
(2) a second connected cylinder including a connected cylinder main body portion having two or more cylinder bores and a coating configured to cover an inner peripheral surface of the connected cylinder main body portion in which the cylinder bores are formed; and

a cylinder block main body having one end side where a crankcase is formed, another end side where a cylinder head is attachable, and a hollow portion passing through the cylinder block main body from the one end side to the another end side,
wherein the connected cylinder is fitted to the hollow portion of the cylinder block main body so as to be removable.

12. The internal combustion engine according to claim 11, wherein the connected cylinder is fitted into the hollow portion of the cylinder block main body through any type of fitting selected from clearance fit and transition fit.

13. The internal combustion engine according to claim 11 or 12,
wherein a coolant passage is formed between two adjacent ones of the cylinder bores of the connected cylinder so as to be located inside an end surface of the connected cylinder on a side where the cylinder head is arranged,
wherein a sectional shape of the coolant passage, which is taken along a plane being parallel to a center line of each of the cylinder bores formed in the connected cylinder, is a slit-like shape.

14. The internal combustion engine according to any one of claims 11 to 13,
wherein fixing flange portions are formed on an outer peripheral surface of the connected cylinder along a direction parallel to a center line of each of cylinder bores formed in the connected cylinder, and
wherein guide grooves to be fitted to the fixing flange portions are formed in an inner peripheral surface of the hollow portion of the cylinder block main body.

15. The internal combustion engine according to claim 14,
wherein the fixing flange portions are formed on the outer peripheral surface so as to be located on both end sides in a direction of arrangement of the cylinder bores, and
wherein the guide grooves are formed in the inner peripheral surface of the hollow portion of the cylinder block main body so as to be located on both end

sides in a longitudinal direction of an opening portion of the hollow portion.

16. The internal combustion engine according to any one of claims 11 to 13,
wherein fixing flange portions are formed on an inner peripheral surface of the hollow portion of the cylinder block main body along a direction parallel to a penetrating direction of the hollow portion, and
wherein guide grooves to be fitted to the fixing flange portions are formed in an outer peripheral surface of the connected cylinder.

17. The internal combustion engine according to claim 16,
wherein the fixing flange portions are formed on the inner peripheral surface of the hollow portion of the cylinder block main body so as to be located on both end sides in a longitudinal direction of an opening portion of the hollow portion, and
wherein the guide grooves are formed in the outer peripheral surface of the connected cylinder so as to be located on both end sides in a direction of arrangement of cylinder bores formed in the connected cylinder.

18. The internal combustion engine according to claim 15 or 17, wherein the internal combustion engine comprises a horizontally-opposed engine.

19. The internal combustion engine according to any one of claims 11 to 18, wherein a coolant jacket is provided between an outer peripheral surface of the connected cylinder and an inner peripheral surface of the hollow portion of the cylinder block main body.

20. The internal combustion engine according to claim 19, wherein a dividing flange portion configured to divide the coolant jacket into two or more portions is formed at least on any surface selected from the outer peripheral surface of the connected cylinder and the inner peripheral surface of the hollow portion of the cylinder block main body.

21. The internal combustion engine according to claim 20, wherein the dividing flange portion has no through hole penetrating in a width direction of the dividing flange portion.

22. The internal combustion engine according to claim 20, wherein the dividing flange portion has a through hole penetrating in a width direction of the dividing flange portion and a closing member capable of closing the through hole.

23. The internal combustion engine according to claim 22, wherein the through hole is closed by the closing member when the internal combustion engine is operated.

24. The internal combustion engine according to any one of claims 20 to 23, wherein no coolant jacket spacer is arranged in the coolant jacket.

25. The internal combustion engine according to any one of claims 20 to 24, wherein a depth D of the coolant jacket is 1/2 times of a total length L of the coolant jacket or smaller in a direction parallel to a center line of each of cylinder bores formed in the connected cylinder.

26. The internal combustion engine according to any one of claims 20 to 25, wherein a depth D of the coolant jacket is 1/2 times of a total length L of the coolant jacket or smaller in a direction parallel to a center line of each of cylinder bores formed in the connected cylinder, and no coolant jacket spacer is arranged in the coolant jacket.

27. A connected cylinder, comprising:

two or more cylinder liners; and
a connecting portion configured to connect the two or more cylinder liners to each other.

28. The connected cylinder according to claim 27, wherein the connected cylinder has a connected ring-like outer peripheral shape having a ring-like portion with a diameter larger than a bore diameter of each of the cylinder liners,
wherein an outer diameter (D1) of a first region formed of an outer peripheral surface from a vicinity of a cylinder head side to a vicinity of a central portion in a direction of a center line of each of the cylinder liners based on the center line of each of the cylinder liners as a reference is larger than an outer diameter (D2) of a second region formed of an outer peripheral surface in a vicinity of a crankcase side based on the center line of each of the cylinder liners as a reference, and
wherein a level difference that is parallel to an outer peripheral direction and is continuous is formed between the first region and the second region.

29. A connected cylinder, comprising:

a connected cylinder main body portion having two or more cylinder bores; and
a coating configured to cover an inner peripheral surface of the cylinder bores, which are formed in the connected cylinder main body portion.

30. The connected cylinder according to claim 29, comprising:

a connected cylinder main body portion having

two or more cylinder bores; and
a coating configured to cover an inner peripheral surface of the cylinder bores, which are formed in the connected cylinder main body portion,
wherein the connected cylinder has a connected ring-like outer peripheral shape having a ring-like portion with a diameter larger than a bore diameter of each of the cylinder bores,
wherein an outer diameter (D1) of a first region formed of an outer peripheral surface from a vicinity of a cylinder head side to a vicinity of a central portion in a direction of a center line of each of the cylinder bores based on the center line of each of the cylinder bores as a reference is larger than an outer diameter (D2) of a second region formed of an outer peripheral surface in a vicinity of a crankcase side based on the center line of each of the cylinder bores as a reference, and
wherein a level difference that is parallel to an outer peripheral direction and is continuous is formed between the first region and the second region.

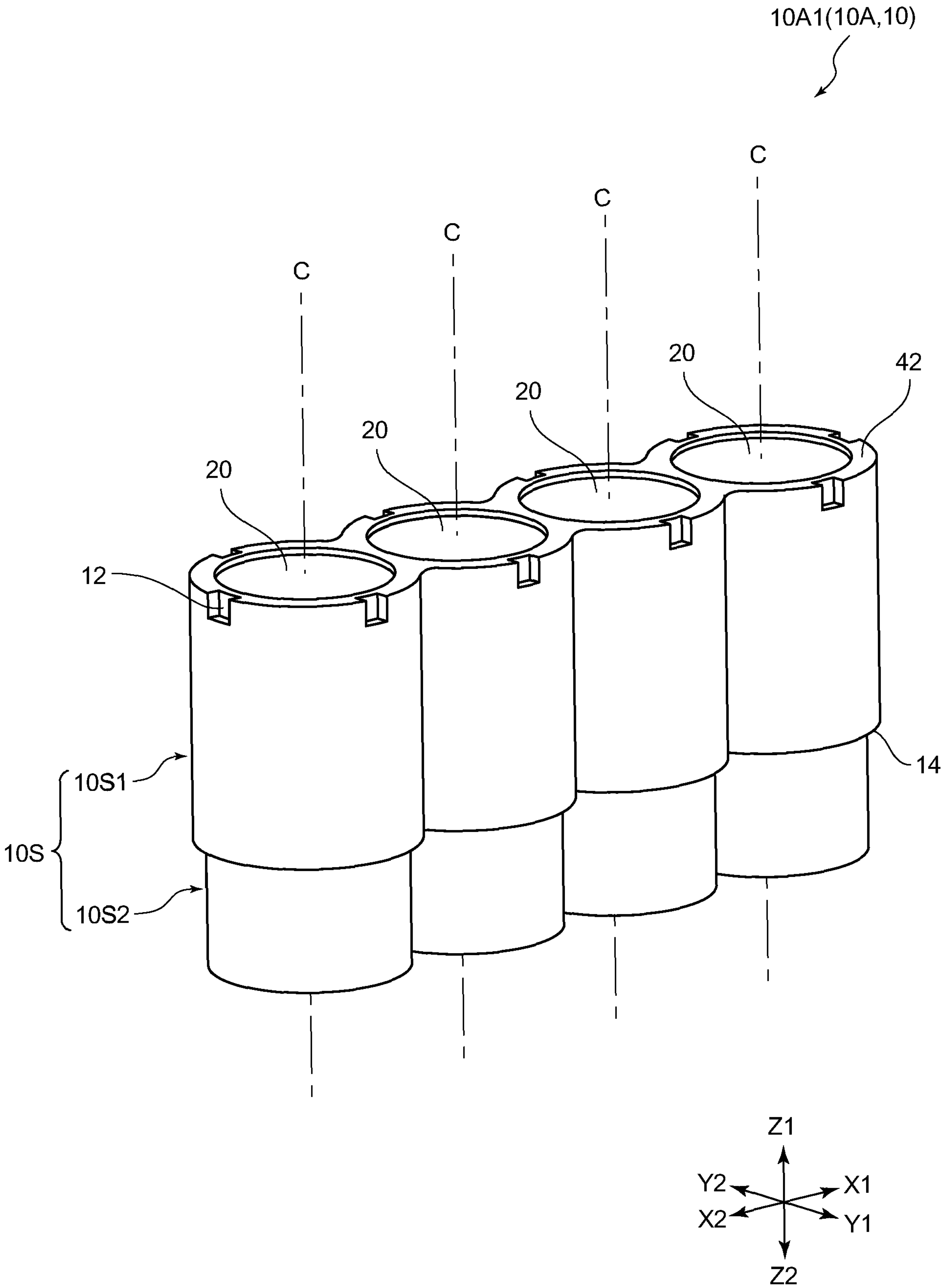
31. The connected cylinder according to any one of claims 27 to 30, further comprising a flange portion formed on an outer peripheral surface.

32. The connected cylinder according to claim 28 or 30, wherein a flange portion that partitions the first region into a region on the cylinder head side and a region on the crankcase side is formed on the first region.

33. The connected cylinder according to claim 31 or 32, wherein the flange portion has no through hole penetrating in a width direction of the flange portion.

34. The connected cylinder according to claim 31 or 32, wherein the flange portion has a through hole penetrating in a width direction of the flange portion and a closing member capable of closing the through hole.

35. The connected cylinder according to any one of claims 27 to 34,
wherein a coolant passage is formed between adjacent two ones of cylinder bores of the connected cylinder so as to be located inside an end surface of the connected cylinder on a side where the cylinder head is arrangeable, and
wherein a sectional shape of the coolant passage, which is taken along a plane being parallel to a center line of each of the cylinder bores formed in the connected cylinder, is a slit-like shape.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20
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Y1
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FIG. 1

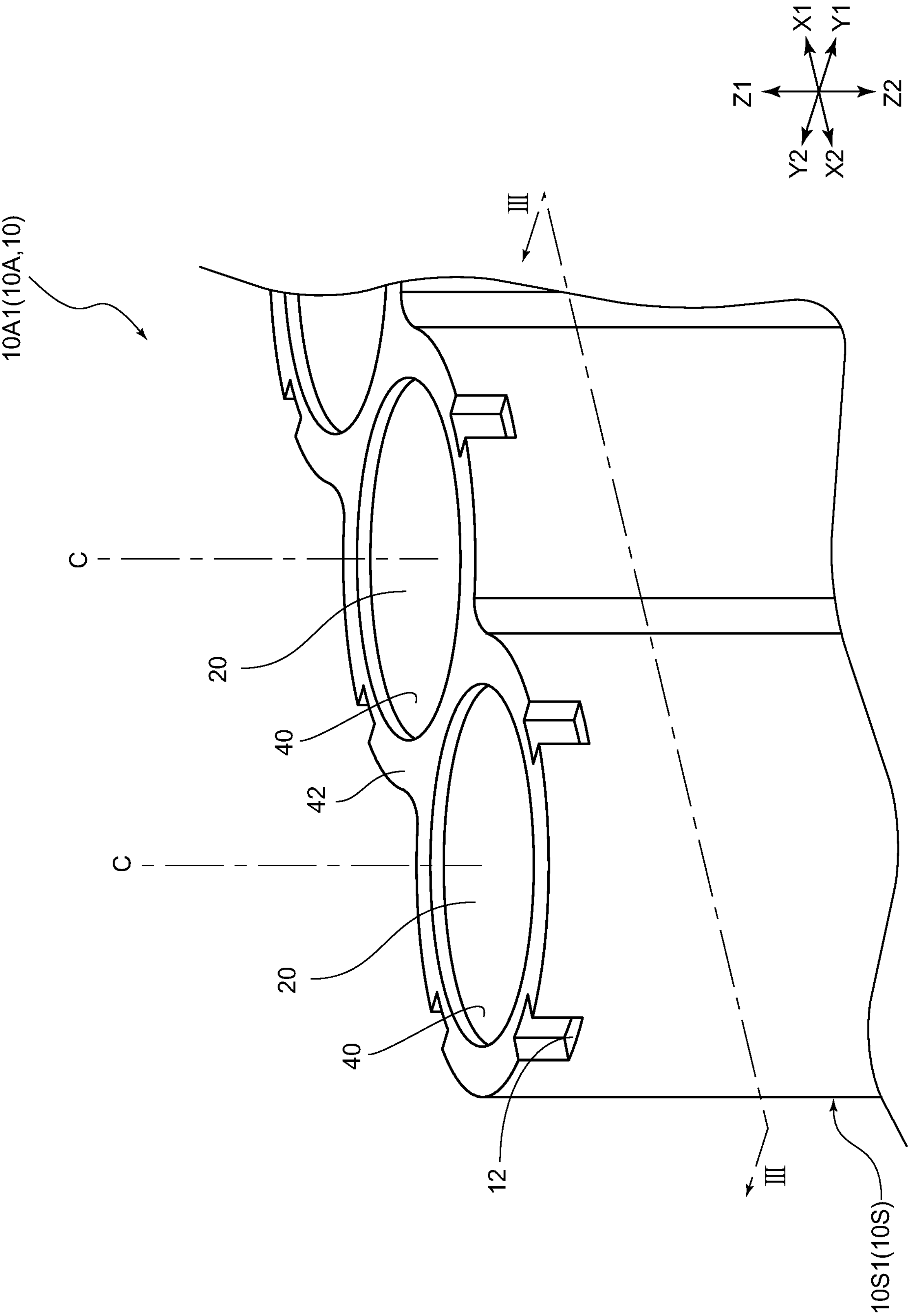

FIG. 2

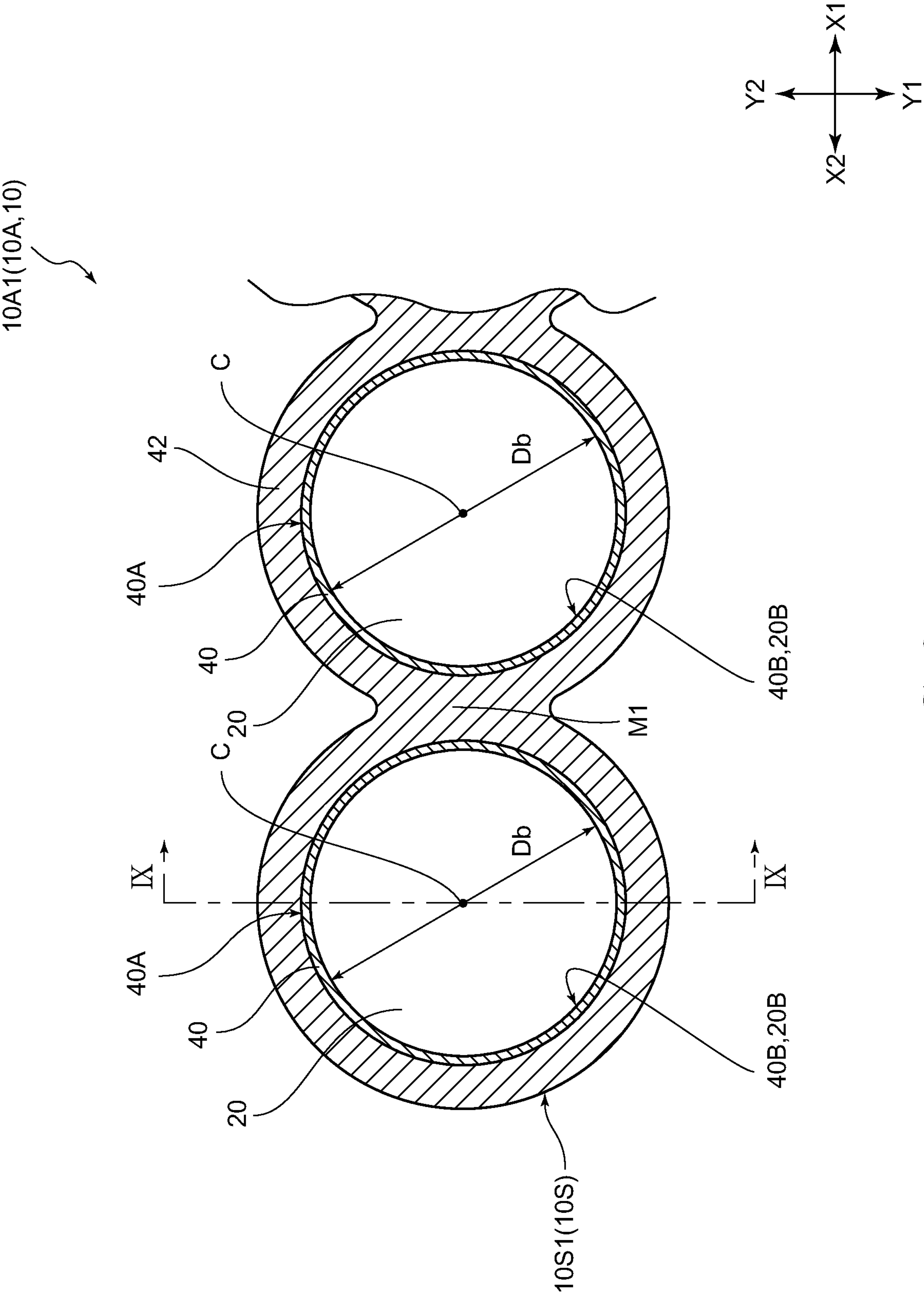
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FIG. 3

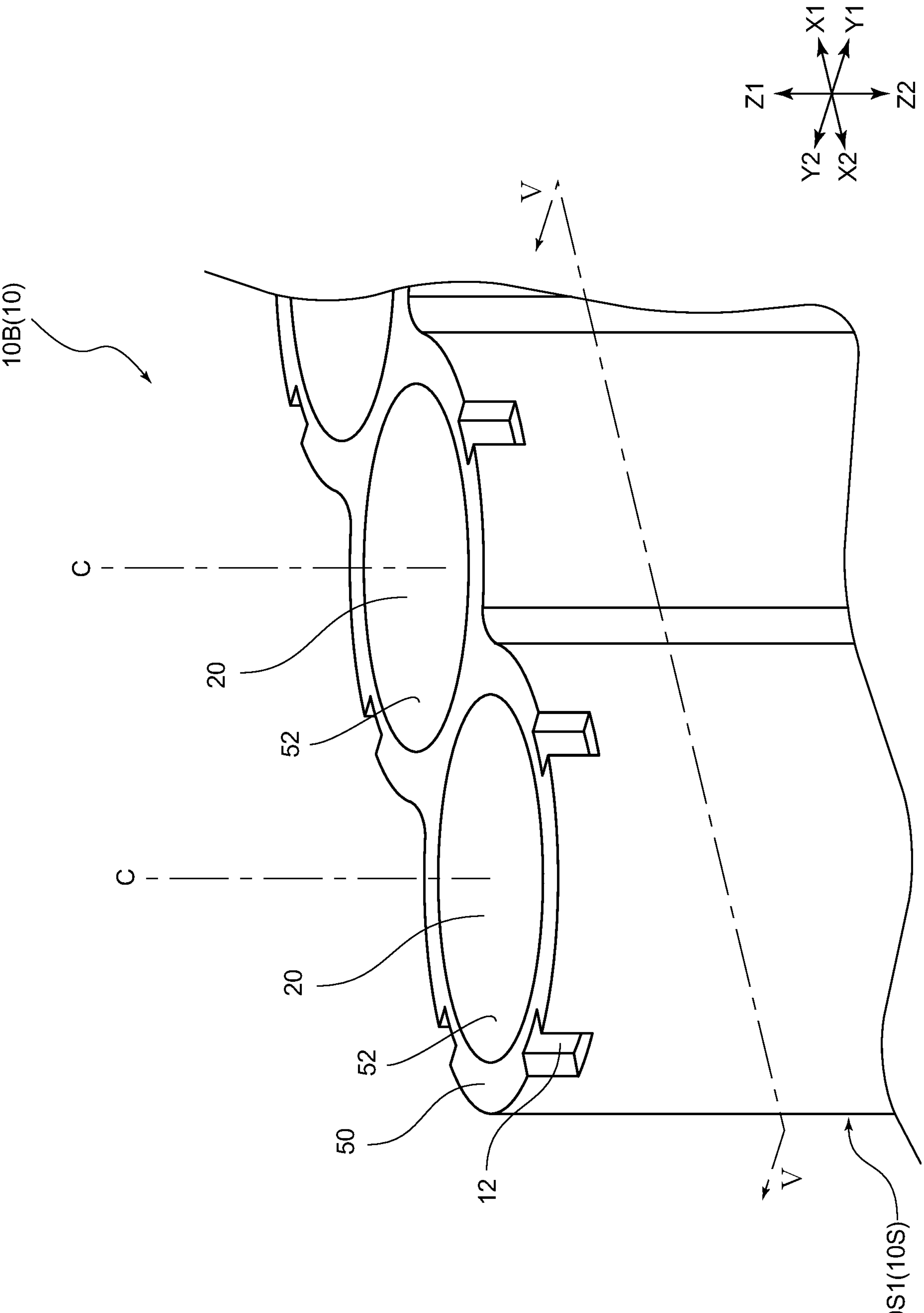
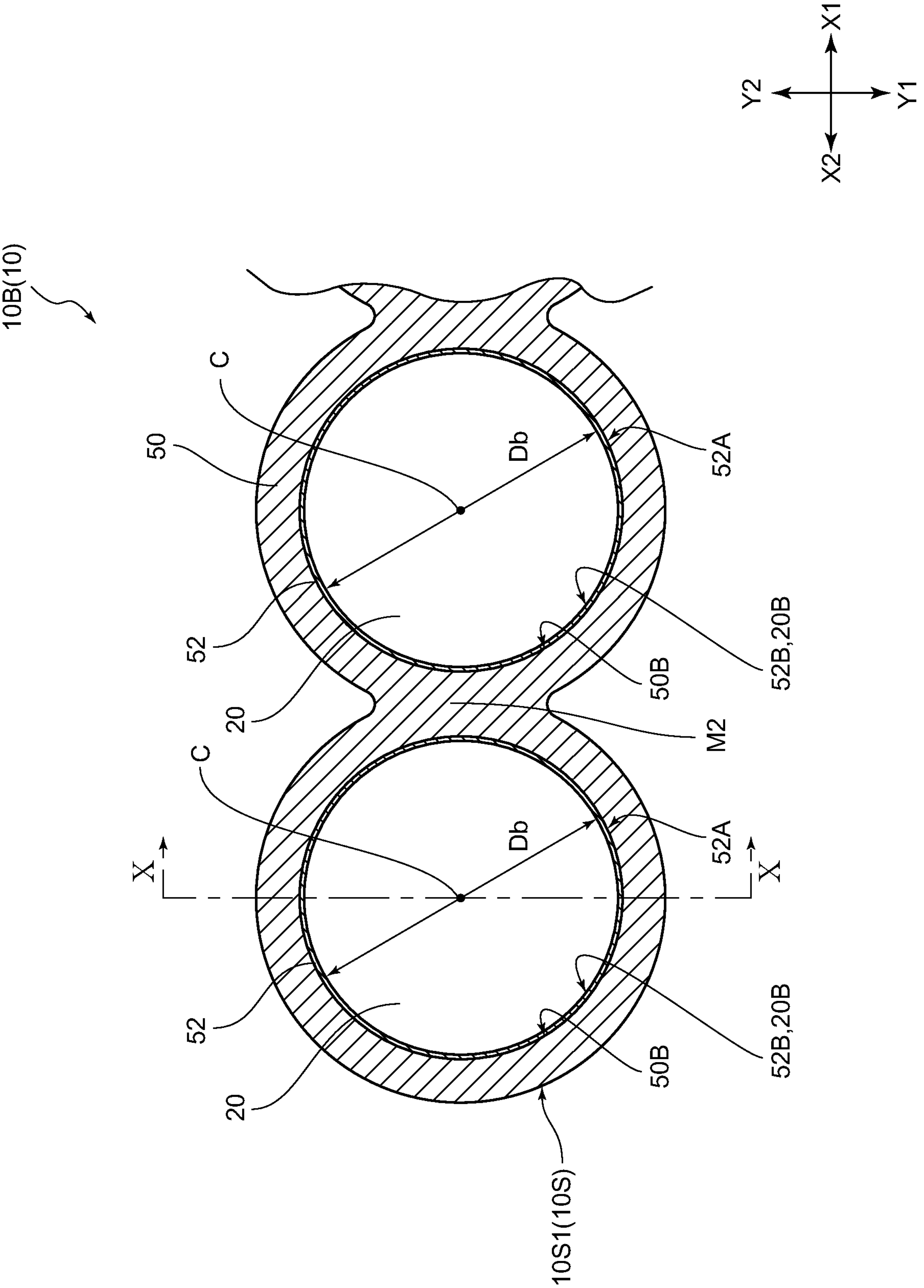


FIG. 4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20
50B
52B,20B
10S1(10S)

FIG. 5

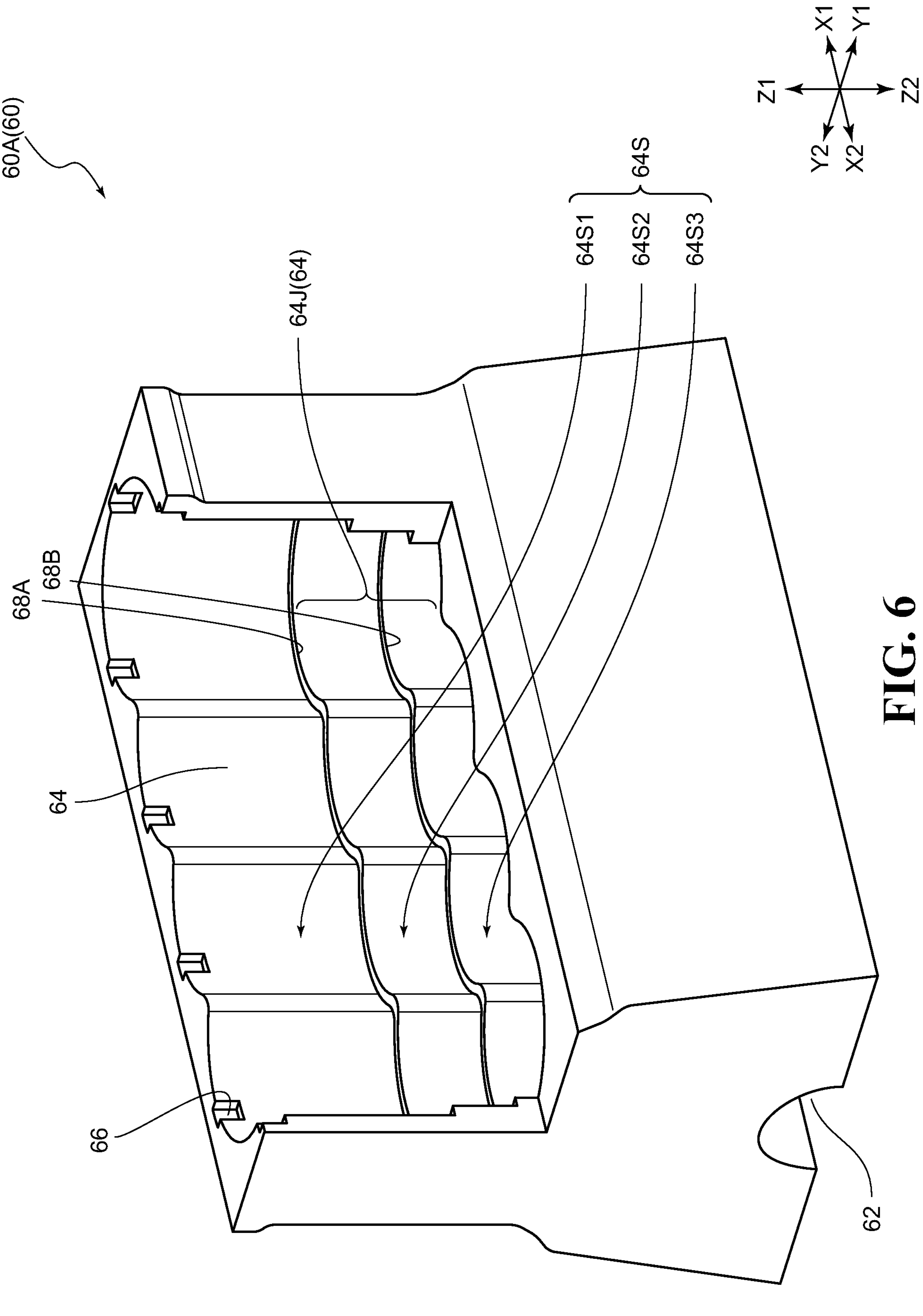


FIG. 6

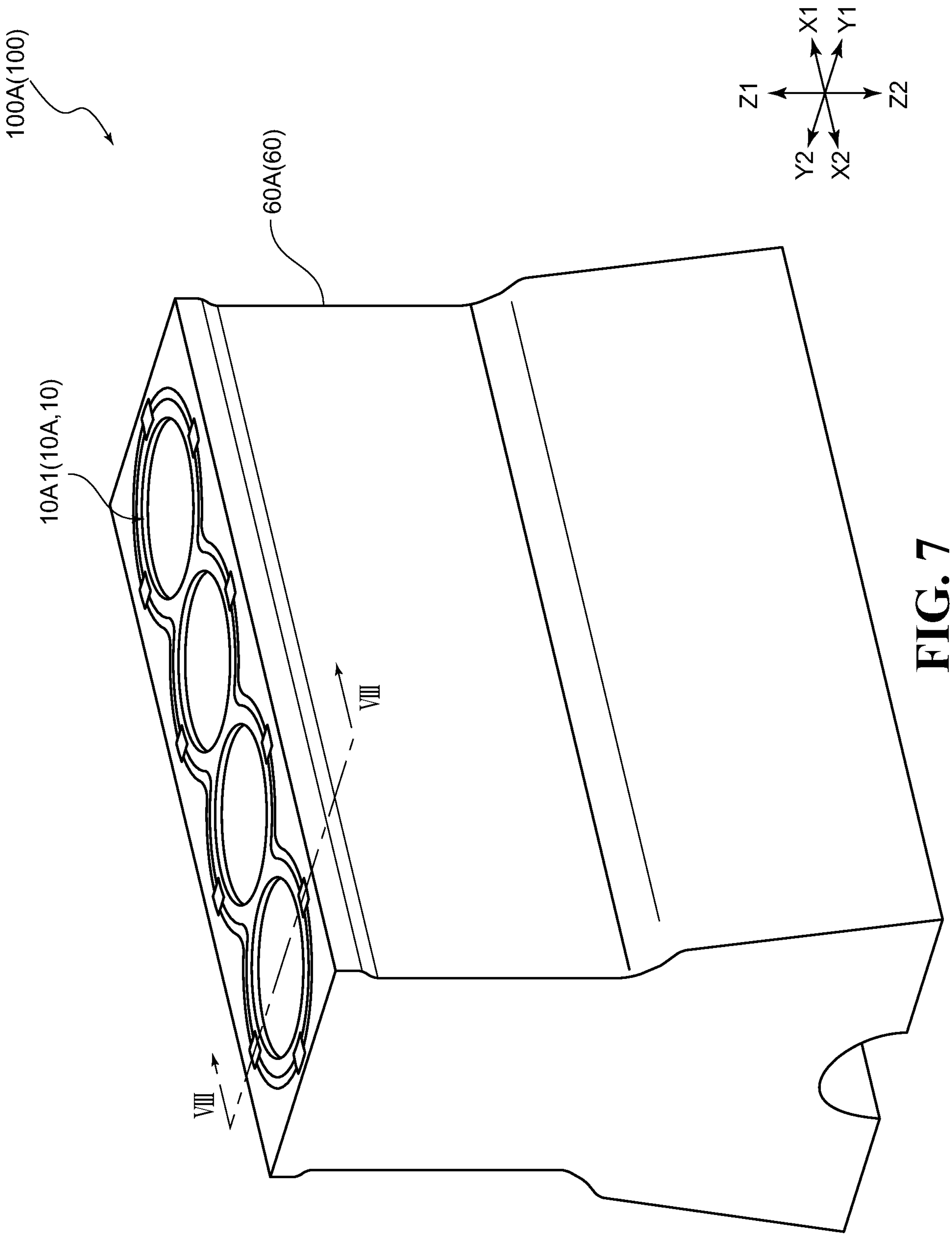


FIG. 7

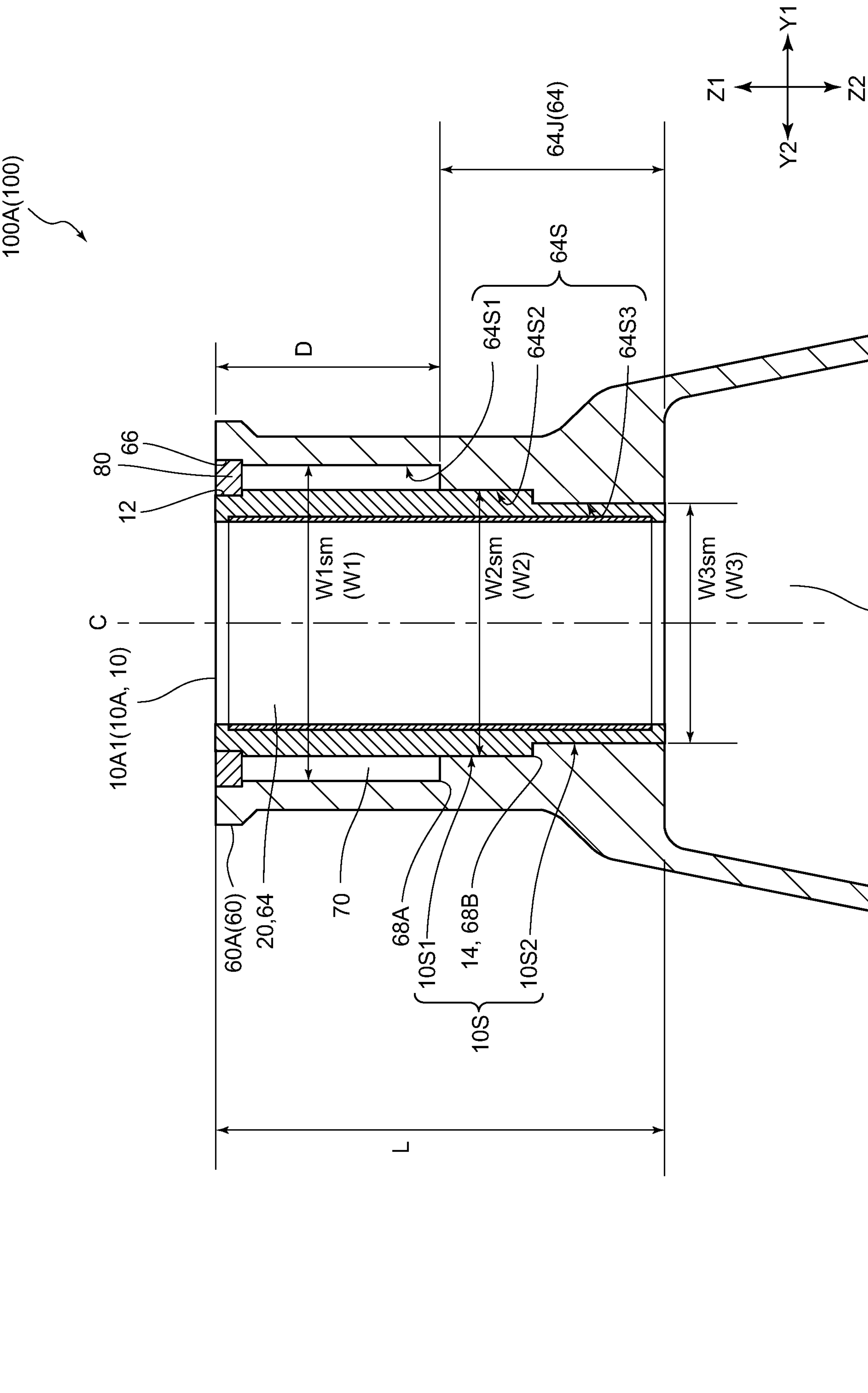

100A(100)
64J(64)
Z1
Z2
Y1
Y2
64S
64S1
64S2
64S3
D
66
80
12
C
10A1(10A, 10)
W1sm
(W1)
W2sm
(W2)
W3sm
(W3)
62
60A(60)
20,64
70
68A
10S1
14, 68B
10S2
10S
L

FIG. 8

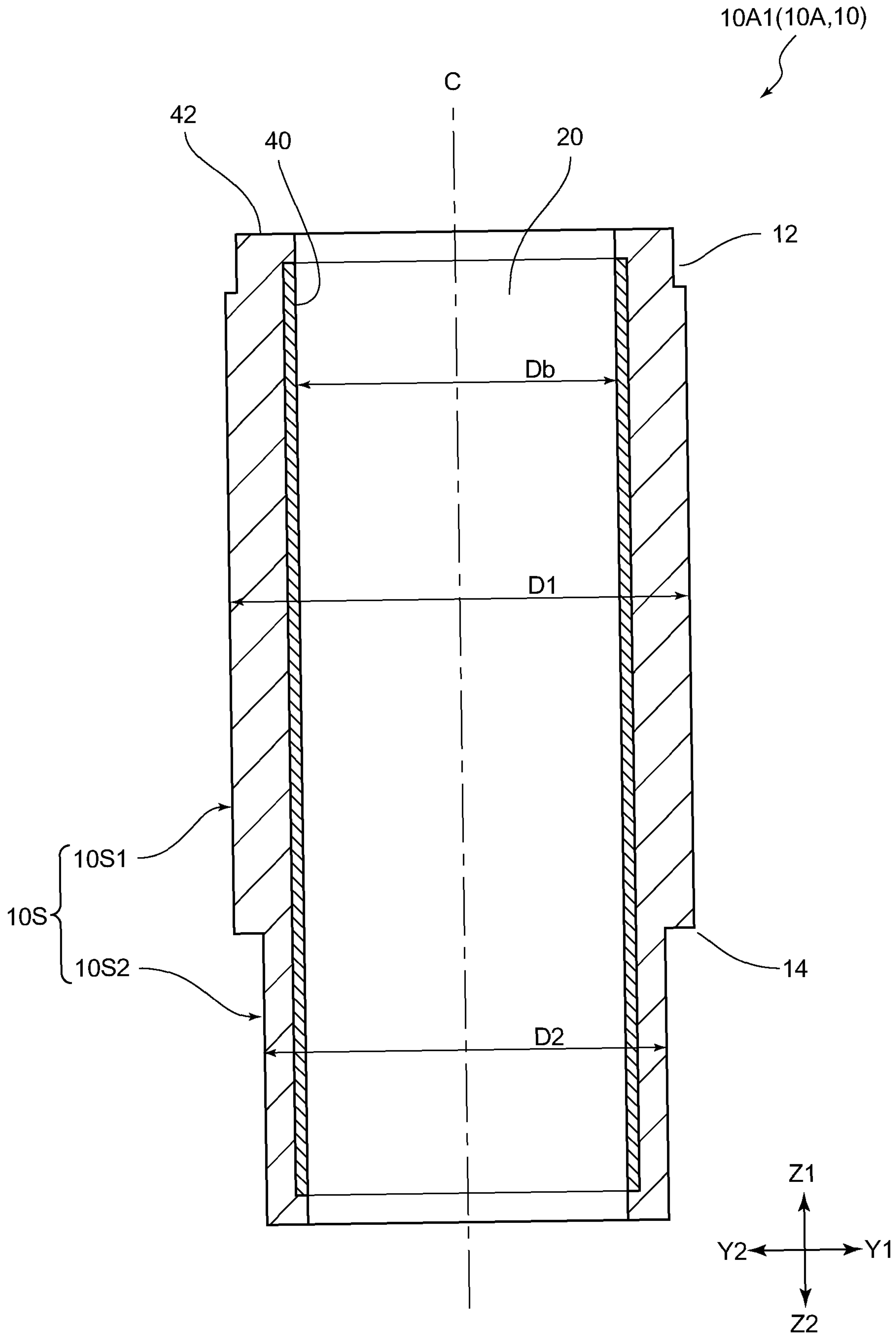


FIG. 9

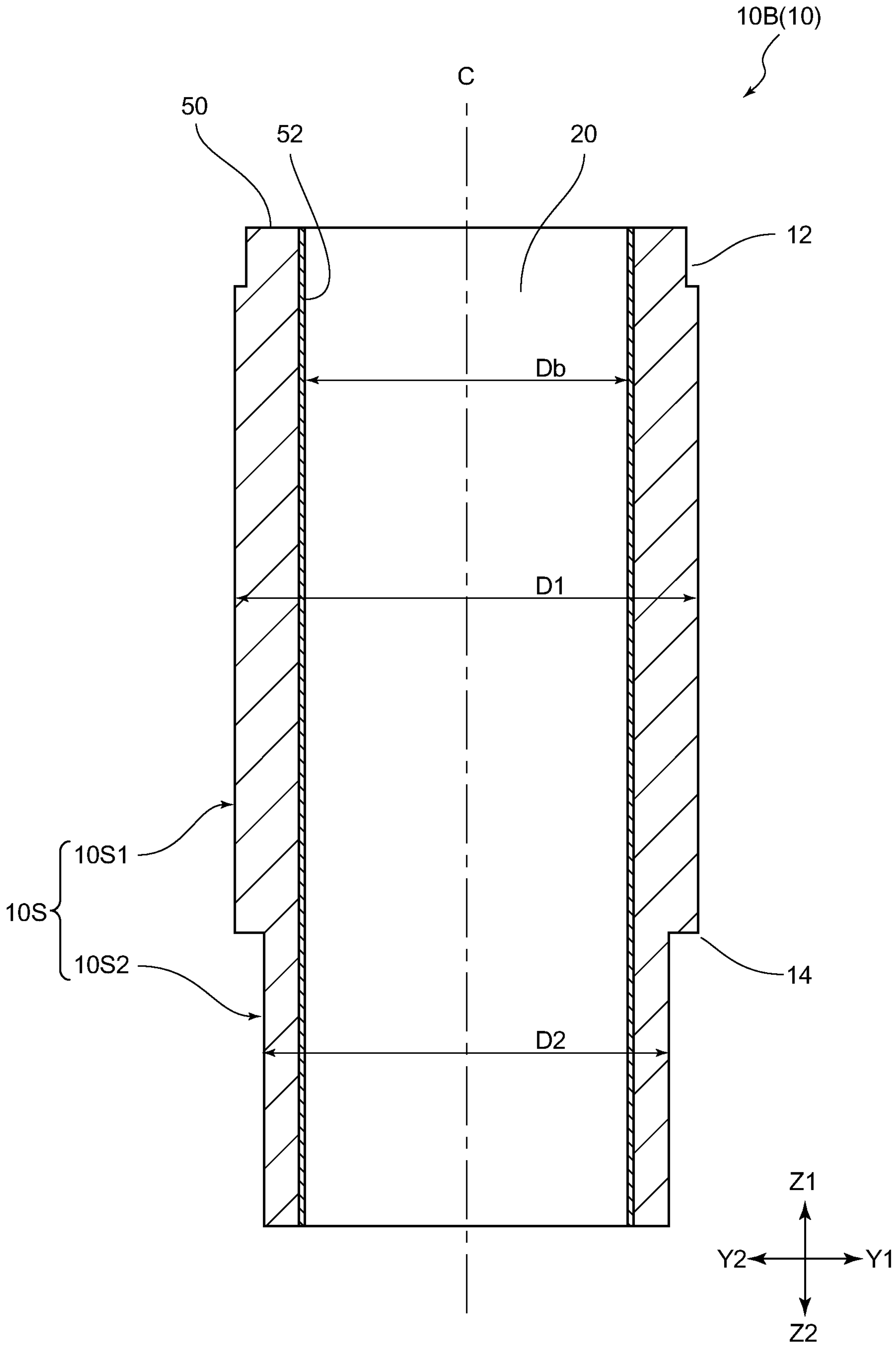


FIG. 10

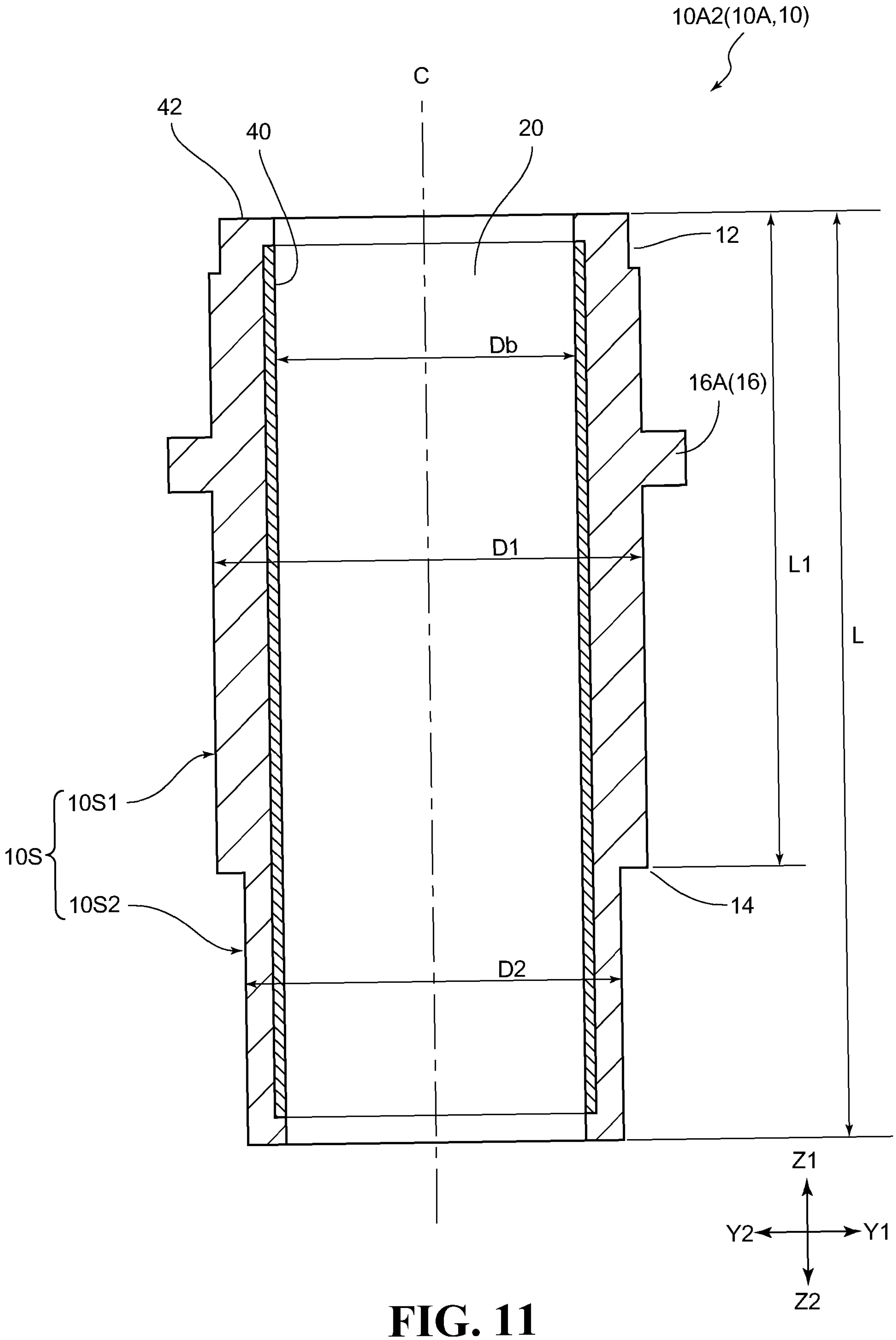

10A2(10A,10)
C
42
40
20
12
Db
16A(16)
D1
L1
L
10S1
10S
10S2
14
D2
Z1
Y2
Y1
Z2

FIG. 11

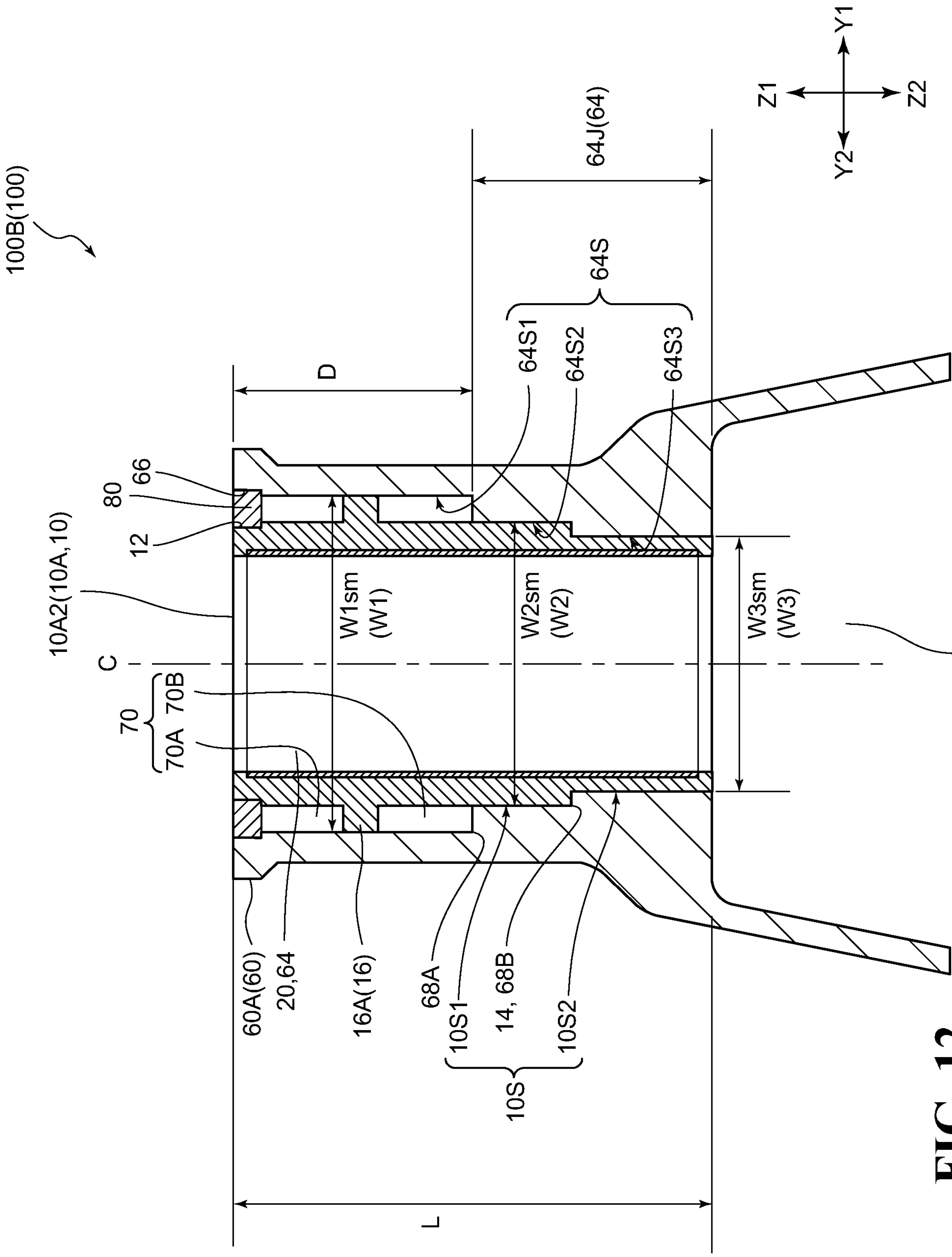

100B(100)
10A2(10A,10)
C
70
70A
70B
12
80
66
D
64S1
64S2
64S3
64S
64J(64)
W1sm
(W1)
W2sm
(W2)
W3sm
(W3)
62
Z1
Z2
Y1
Y2
60A(60)
20,64
16A(16)
68A
10S1
14, 68B
10S2
10S
L

FIG. 12

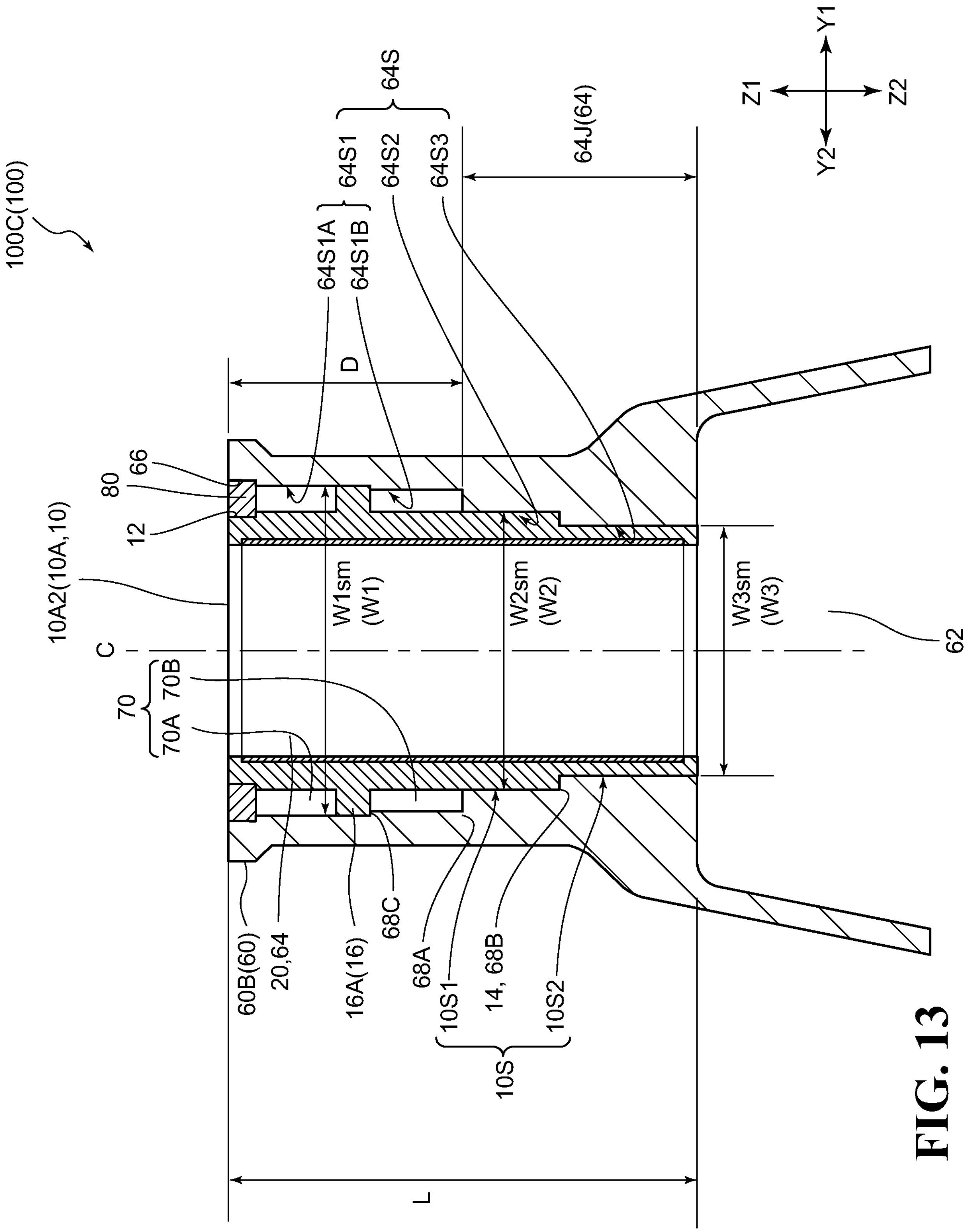

100C(100)
10A2(10A,10)
C
70
70A
70B
12
80
66
64S1A
64S1B
64S1
64S2
64S3
64S
D
64J(64)
W1sm
(W1)
W2sm
(W2)
W3sm
(W3)
62
Z1
Z2
Y1
Y2
60B(60)
20,64
16A(16)
68C
68A
10S1
14, 68B
10S2
10S
L

FIG. 13

FIG. 14A

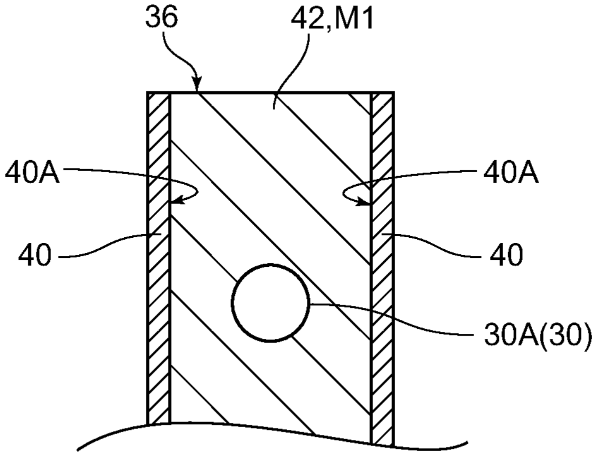


FIG. 14B

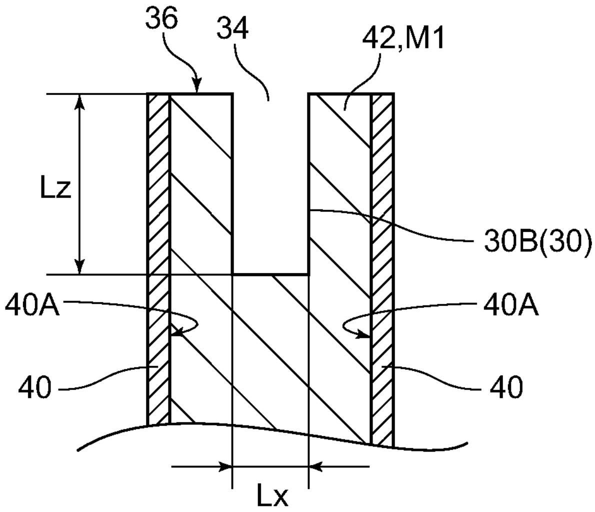
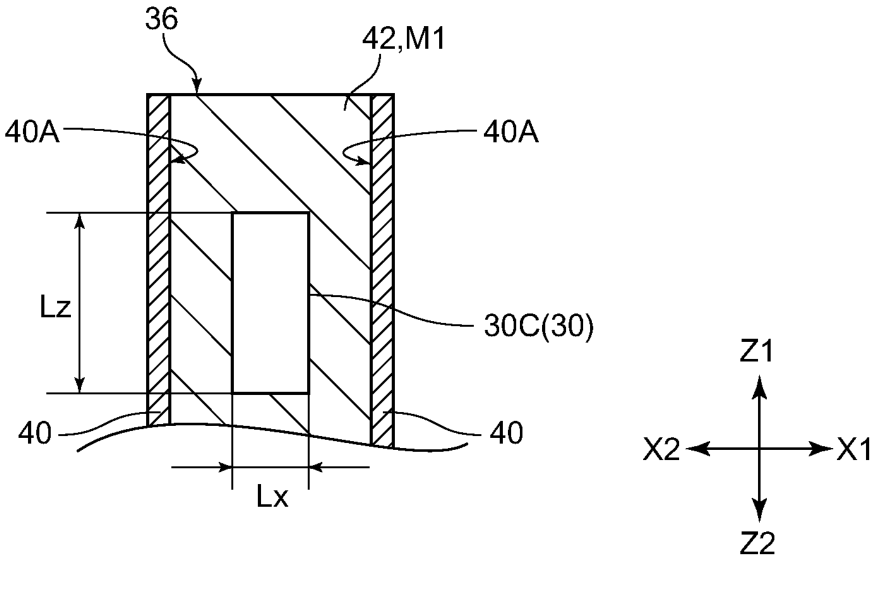


FIG. 14C



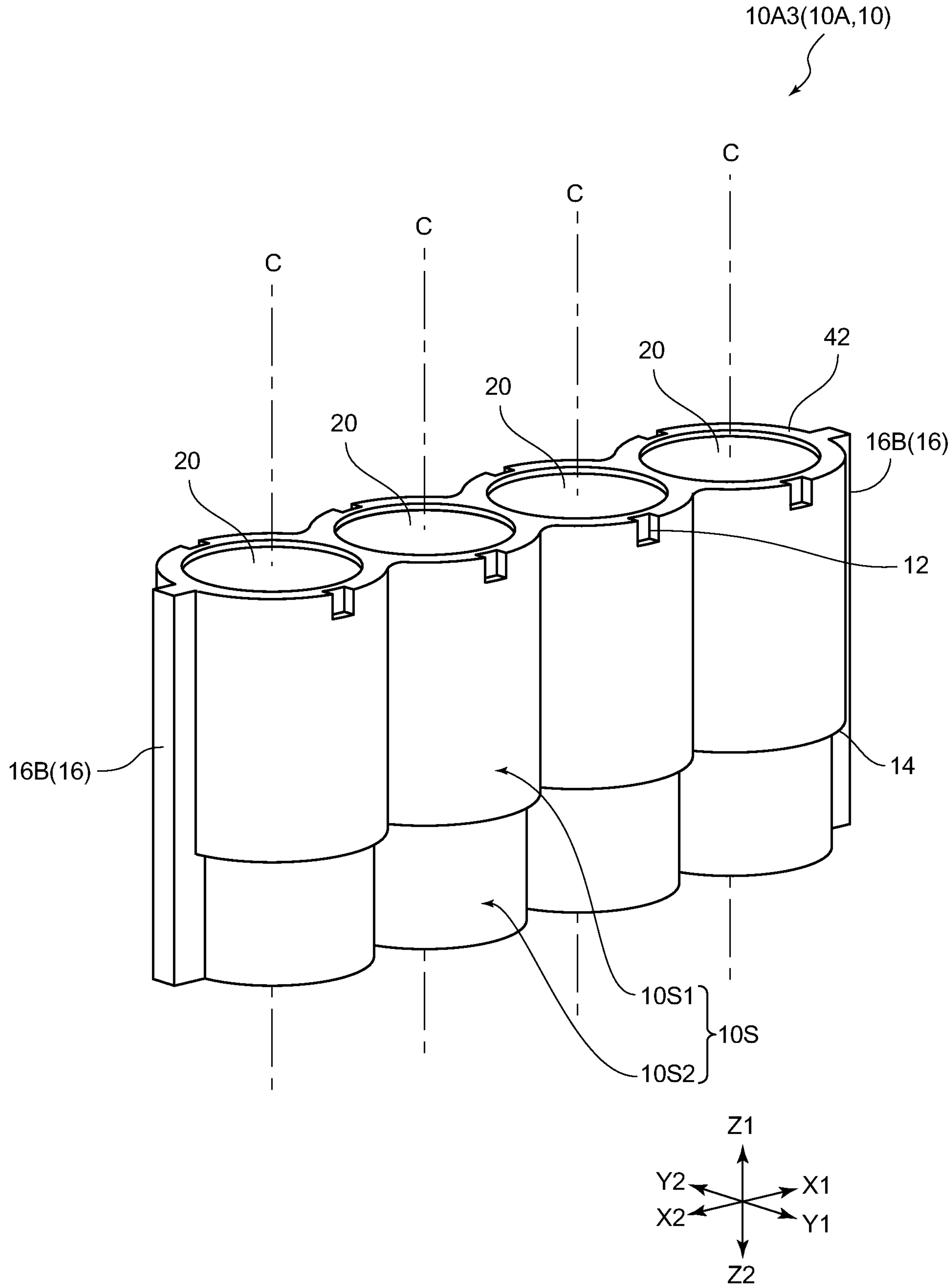

10A3(10A,10)
C
C
C
C
20
20
20
20
42
16B(16)
12
16B(16)
14
10S1
10S
10S2
Z1
Y2
X1
X2
Y1
Z2

FIG. 15

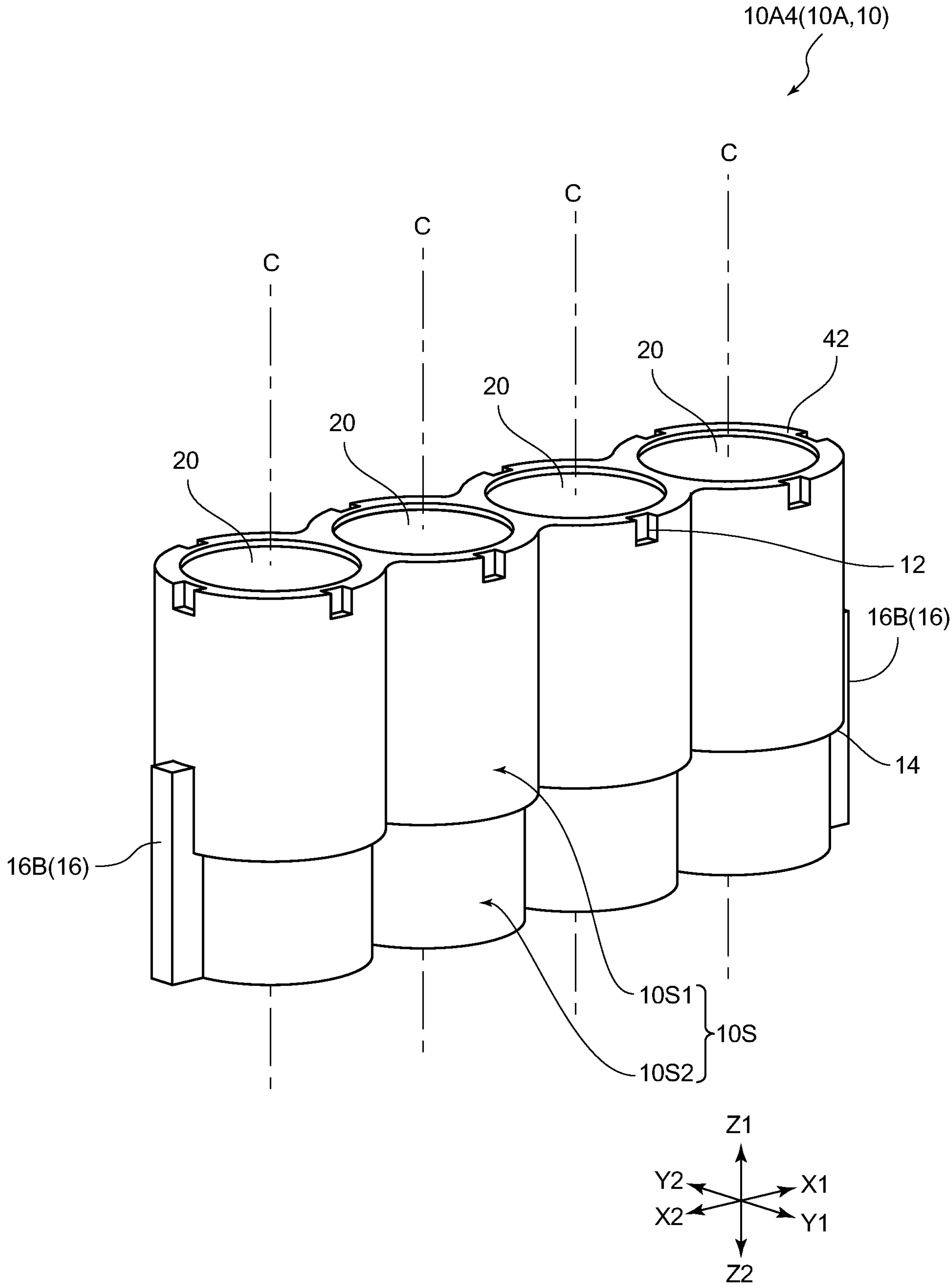

10A4(10A,10)
C
C
C
C
20
20
20
20
42
12
16B(16)
16B(16)
14
10S1
10S2
10S
Z1
Y2
X1
X2
Y1
Z2

FIG. 16

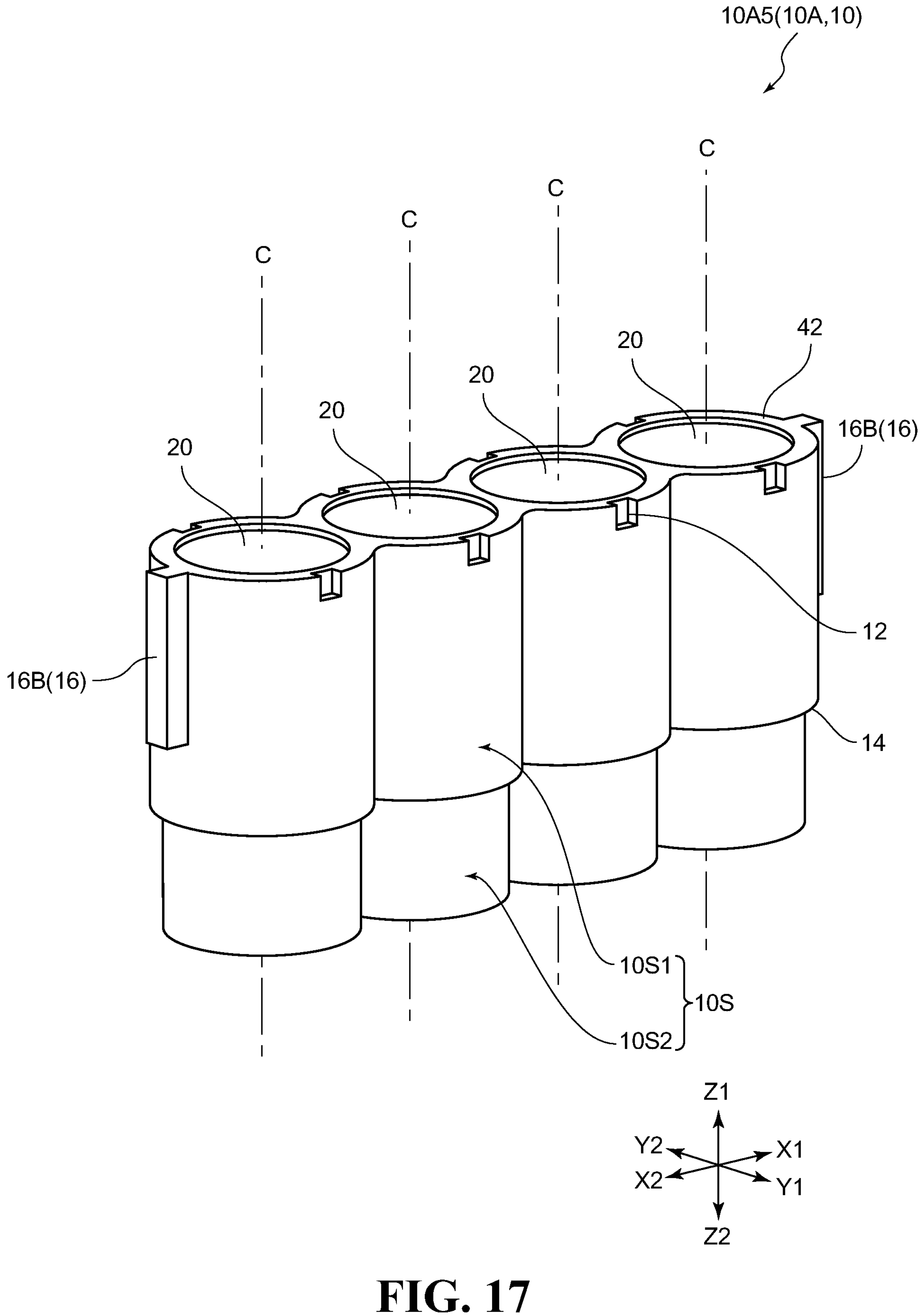

10A5(10A,10)
C
C
C
C
20
20
20
20
42
16B(16)
16B(16)
12
14
10S1
10S
10S2
Z1
Y2
X1
X2
Y1
Z2

FIG. 17

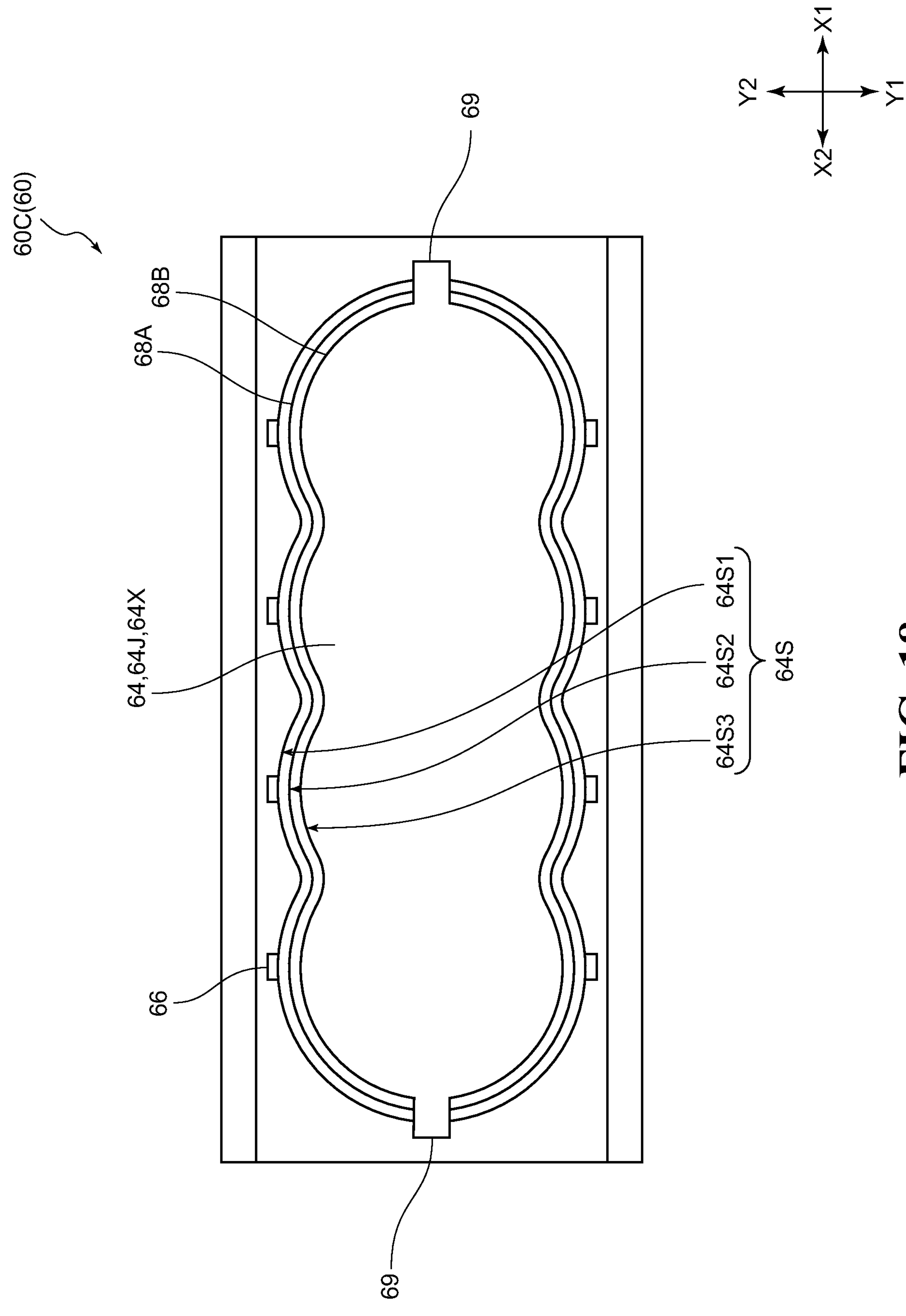


FIG. 18

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/001243

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl. F02F1/00(2006.01)i

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)
Int. Cl. F02F1/00

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2018
Registered utility model specifications of Japan	1996-2018
Published registered utility model applications of Japan	1994-2018

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.
X Y	JP 2006-312905 A (TOYOTA MOTOR CORP.) 16 November 2006, paragraphs [0021]-[0057], fig. 1-4 (Family: none)	1-2, 11-12, 27, 29 3-10, 13-26, 28, 30-35
Y	JP 8-246944 A (SUZUKI MOTOR CORP.) 24 September 1996, paragraph [0027] (Family: none)	3-10
Y	JP 2004-36511 A (TOYOTA MOTOR CORP.) 05 February 2004, paragraphs [0011]-[0036] (Family: none)	8-10
Y	JP 60-94230 A (TOYOTA MOTOR CORP.) 27 May 1985, fig. 2, 3 (Family: none)	10, 13-26, 35

☒ 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	Date of mailing of the international search report
07.02.2018	20.02.2018

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/001243

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2005-307953 A (TOYOTA MOTOR CORP.) 04 November 2005, fig. 6-8 (Family: none)	14-26
Y	JP 2005-201084 A (TOYOTA MOTOR CORP.) 28 July 2005, fig. 3, 4 & WO 2005/068814 A1, fig. 3, 4	20-26, 31-35
Y	JP 5-296103 A (NISSAN MOTOR CO., LTD.) 09 November 1993, paragraphs [0028], [0035], fig. 1, 4, 7 (Family: none)	25-26
Y	JP 9-96245 A (SUZUKI MOTOR CORP.) 08 April 1997, fig. 1, 2 (Family: none)	28, 30-35
A	JP 11-101155 A (FUJI HEAVY INDUSTRIES LTD.) 13 April 1999, paragraphs [0010]-[0012] (Family: none)	1-35

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Patent documents cited in the description

- JP 2813947 B **[0003]**
- JP 4278125 B **[0003]**