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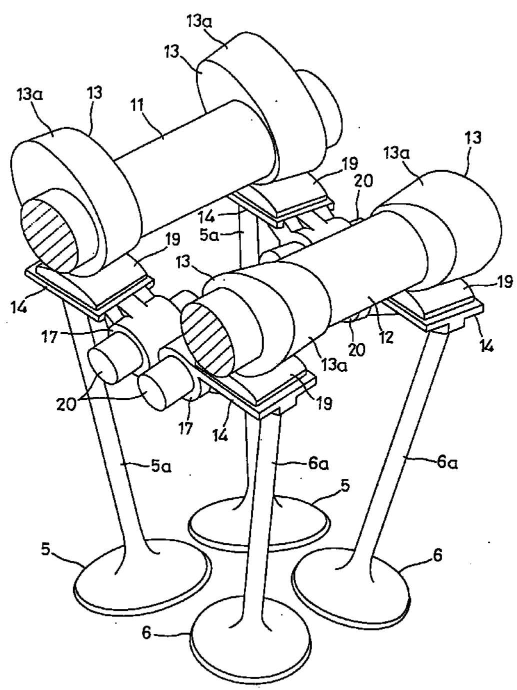
(54) Three-dimensional cam device and method of making a three-dimensional cam for a valve drive system for engines

(57) A three-dimensional cam device having a cam follower adapted to rock in a direction inclined with respect to the direction of displacement of a cam surface of a three-dimensional cam. The sliding surface of the cam follower is in the form of a convex of an arcuate cross-section when viewed from the axial direction of a rocker shaft, and at least a pad of the cam surface is formed with a concave surface such that the axially central portion of a three-dimensional cam is curved inward from other portions.

[FIG. 3]



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Description

[0001] This invention relates to a three-dimensional cam device having a cam follower adapted to rock in a direction inclined with respect to the direction of displacement of a cam surface of a three-dimensional cam and to a method of making a three-dimensional cam for a valve drive system for engines in which the outer circumferential surface of a three-dimensional cam is ground by the outer circumferential surface of a grindstone, with the axis of the grindstone being inclined with respect to the axis of the three-dimensional cam.

[0002] The three-dimensional cam device of this kind has been utilized in the valve drive system having, for example more than four intake and exhaust valves disposed radially in a cylinder.

[0003] In such a valve drive system, stroking directions of the intake and exhaust valves are different for each valve when viewed from the direction perpendicular to the axes of the cam shafts, therefore each cam is formed in the shape of a three-dimensional cam and the rocker arm interposed between the cam and the intake or exhaust valve is inclined so as to correspond to the intake or exhaust valve. That is, the rocker arm is pressed down in an oblique direction by the three-dimensional cam.

[0004] The cam surface of the three-dimensional cam is formed by grinding the outer circumferential surface of the cam with a grindstone having an axis inclined with respect to the cam axis. During grinding, the grindstone is rotated slowly so as to change its grinding position, and parallel-translated to the cam so as to correspond the cam profile. That is, the grindstone is parallel-translated in a direction of engagement/disengagement of the grindstone with respect to the cam surface, with the axis of the grindstone inclined with respect to the cam shaft, to grind the cam surface.

[0005] However, the conventional valve drive system using the three-dimensional cam as described above, has a problem that the top of the cam, or the portion of the cam surface with the smallest radius of curvature is apt to wear over the other portions.

[0006] The reason why part of the cam surface is apt to wear is that the moving speed of the cam surface relative to the sliding surface of the rocker arm is lowered at that part, thereby breaking the oil film between them.

[0007] In order to solve such a drawback, a system should be adopted such that a two-dimensional cam is employed and the rotation of the cam is transmitted to each valve through two kinds of rocker arms with different operational directions, as shown, for example, in Japanese Unexamined Patent Publication Sho 59-29709. However, incorporation of this system results in higher manufacturing costs and larger size because of the number of the rocker arms being large.

[0008] Accordingly, it is an objective of the present invention to provide a three-dimensional cam device as indicated above which with simple technical means prevents the development of partial wear of the cam surface and facilitates a smaller size as well as a cost reduction.

[0009] According to the present invention, this objective is solved for a three-dimensional cam device as indicated above in that the sliding surface of the cam follower is in the form of a convex of an arcuate cross-section when viewed from the axial direction of a rocker shaft, and at least a pad of the cam surface is formed with a concave surface such that the axially central portion of a three-dimensional cam is curved inward from other portions.

[0010] This invention is achieved as a result of findings that breakage of the oil film causing partial wear can be eliminated by forming a concave on the cam after numerous experiments have been made repeatedly to obtain a three-dimensional cam developing no partial wear.

[0011] That is, it has been found that the concave in the cam surface is brought into contact with the sliding surface constituted by a convex of the cam follower so that the state of contact comes to be in line contact, thereby retaining the oil film of lubricating oil between the cam surface and the sliding surface reliably. The state of line contact is maintained even if the cam follower moves in a direction inclined with respect to the direction of displacement of the cam surface.

[0012] A three-dimensional cam according to another embodiment of the invention is characterized in that a portion of the cam surface with a smaller radius of curvature is formed with a concave.

[0013] According to this invention, the state of contact of a portion at the top of the cam where surface pressure is relatively high, can be turned to be in line contact.

[0014] The use of the cam device according to the present invention for a valve drive system for engines is characterized in that rocker arms supported on a cylinder head for rocking movement constitute the cam followers, and a plurality of intake and exhaust valves disposed radially in a cylinder are driven by said cams and rocker arms.

[0015] According to this invention, radial type intake and exhaust valves can be driven by the three-dimensional cams with improved lubricating ability.

[0016] It is a further objective of the present invention to provide a method of making a three-dimensional cam as indicated above preventing the development of partial wear of the cam surface.

[0017] According to the present invention, this objective is solved for a method of making a three-dimensional cam as indicated above in that a cam shaft is rotated at relatively low speed during grinding, and at least one of the grindstone and the three-dimensional cam is parallel-translated in a direction of engagement/disengagement of said components, and in a direction perpendicular to said direction of engagement/disengagement and to the axis of the grindstone, to determine the position of the grindstone with respect to the three-dimensional cam during grinding

[0018] A method of making a three-dimensional cam for a valve drive system for engines according to the invention is characterized by said method of making a three-dimensional cam in which the outer circumferential surface of a three-dimensional cam is ground by the outer circumferential surface of a grindstone, with the axis of the grindstone inclined with respect to the axis of the three-dimensional cam, wherein the cam shaft is rotated at relatively low speed during grinding, and at least one of the grindstone and the three-dimensional cam is parallel-translated in a direction of engagement/disengagement of said components, and in a direction perpendicular to said direction of engagement/disengagement and to the axis of the grindstone, to determine the position of the grindstone with respect to the three-dimensional cam during grinding.

[0019] According to this invention, any portion of the cam surface can be formed with a concave curved inward at the axially central portion of the three-dimensional cam from other portions.

[0020] A method of making a three-dimensional cam for a valve drive system for engines according to another embodiment of the invention is characterized in that the position of the grindstone with respect to the three-dimensional cam during grinding is changed such that it follows the same locus as the cam follower driven by the three-dimensional cam.

[0021] According to this invention, the cam surface can be formed in imitation of the cam follower being engaged with the cam surface.

[0022] A method of making a three-dimensional cam for a valve drive system for engines according to a further embodiment of the invention is characterized in that a grindstone is used having approximately the same radius as the radius of curvature of the sliding surface of the cam follower; and a still further method of making a three-dimensional cam for a valve drive system for engines is characterized in that a grindstone is used having a radius smaller than the radius of curvature of the sliding surface of the cam follower, and the position of the grindstone with respect to the three-dimensional cam during grinding is changed such that it follows a ground line which appears when the cam surface is ground by a grindstone with a radius nearly equal to the radius of curvature of the sliding surface of the cam follower.

[0023] According to these embodiments, the radius of curvature of the concave of the three-dimensional cam is likely to coincide with that of the sliding surface of the cam follower, and the three-dimensional cam and the cam follower can be brought into line contact with each other at any cam angle at all times.

[0024] Another method of making a three-dimensional cam for a valve drive system for engines according to the invention is characterized in that a cam shaft is used which is formed with a plurality of three-dimensional cams and bearing journals respectively spaced axially, and the three-dimensional cam is ground, with one end of the cam shaft supported on a rotational drive support member of a grinding apparatus, and with one of said journals at the side of the other end of the cam shaft from the three-dimensional cam to be ground, supported by a holder of the grinding apparatus.

[0025] According to this invention, the three-dimensional cam can be ground while supported at both sides thereof in the axial direction.

[0026] Other preferred embodiments of the present invention are laid down in further dependent claims.

[0027] In the following, the present invention is explained in greater detail with respect to several embodiments thereof in conjunction with the accompanying drawings, wherein:

Fig. 1 is a sectional view of the cylinder head with a valve drive system constituted by the three-dimensional cam device according to the invention;

Fig. 2 is a plan view of the cylinder head;

Fig. 3 is a perspective view showing the structure of the valve drive system;

Fig. 4 are views showing the rocker arm;

Fig. 5 is a side view showing the movement of the three-dimensional cam and the rocker arm;

Fig. 6 is an enlarged perspective view of the slipper section of the rocker arm;

Fig. 7 is a perspective view illustrating the method of making the three-dimensional cam;

Fig. 8 is a diagram showing a locus of the grindstone;

Fig. 9 is a structural diagram showing grinding positions of the grindstone;

Fig. 10 is a perspective view showing a state of grinding;

Fig. 11 shows diagrams of the three-dimensional cam being ground; and

Fig. 12 is an illustration of an embodiment in which grinding is performed using a grindstone with a small diameter.

[0028] Now, a first embodiment of the three-dimensional cam device according to this invention will be described in detail with reference to Figs. 1-11. Here, description is made on an example in which the three-dimensional cam device according to this invention is applied to a valve drive system for engines.

[0029] Fig. 1 is a sectional view of the cylinder head with a valve drive system constituted by the three-dimensional cam device according to the invention. Fig. 2 is a plan view of the cylinder head, in which is shown the broken position of Fig. 1 by the line I-I. Fig. 3 is a perspective view showing the structure of the valve drive system. Fig. 4 are views showing the rocker arm, and the figure (a) a plan view, (b) a side view, and (c) a front view as seen from the slipper side. Fig. 5 is a side view showing the movement of the three-dimensional cam and the rocker arm. Fig. 6 is an enlarged perspective view of the slipper section of the rocker arm. Fig. 7 is a perspective view illustrating the method of making the three-dimensional cam, Fig. 8 is a diagram showing a locus of the grindstone, Fig. 9 is a structural diagram showing grinding positions of the grindstone, and Fig. 10 a perspective view showing a state of grinding, with part of the cam being broken away. Fig. 11 shows diagrams of the three-dimensional cam being ground, and the figure (a) is a plan view, (b) a sectional view of the cam shaft and the holder taken along the line B-B of the figure (a).

[0030] In these figures, numeral 1 designates a cylinder head of an engine according to this embodiment. The cylinder head 1 is for a water-cooled single cylinder DOHC type engine, and formed with an approximately semi-spherical combustion chamber 2, and two sets of an intake port 3 and exhaust port 4 connected to the combustion chamber 2. Between these ports 3, 4, that is, at the center of the combustion chamber 2 is attached an ignition plug (not shown).

[0031] Two intake valves 5 for opening/closing the intake ports 3 and two exhaust valves 6 for opening/closing the exhaust ports 4 are disposed such that valve shafts or stems 5a, 6a extend radially from the combustion chamber 2 when viewed from the axial direction of the cylinder, as shown in Fig. 2. These intake and exhaust valves 5, 6 are driven by a valve drive system 7 as described hereinafter. The axis of the cylinder is shown in Fig. 1 by the single dot and dash line C.

[0032] The components through which valve stems 5a, 6a of the intake and exhaust valves 5, 6 pass, as indicated in Fig. 1 by numeral 8, are spring retainers for retaining valve springs (not shown) for biasing the intake and exhaust valves 5, 6 in the direction of valve closing. The spring retainer 8 is formed in a bottomed-cylindrical shape with a bottom (upper side in Fig. 1) penetrated by the intake or exhaust valve 5 or 6, and fitted for sliding movement in a retaining cylinder 9 fixed to the cylinder head 1. The valve spring is spring-loaded between the inner bottom of the spring retainer 8 and the cylinder head 1.

[0033] The valve drive system 7 for driving the intake and exhaust valves 5, 6 comprises an intake cam shaft 11 and exhaust cam shaft 12, and rocker arms 14, one for each of the intake and exhaust valves, engaged by three-dimensional cams 13 of these cam shafts 11, 12.

[0034] The intake cam shaft 11 and exhaust cam shaft 12, as shown in Fig. 2, are provided with the three-dimensional cams 13 at positions corresponding to the intake and exhaust valves 5, 6 and with bearing journals 11a, 12a between these three-dimensional cams 13 and at both ends, and supported for rotation on the cylinder head 1 by a well-known conventional support structure. Cam caps journaling these cam shafts 11, 12 on the cylinder head 1 are designated by numeral 15 in Figs. 1 and 2. These cam shafts 11, 12 are each arranged such that a timing chain sprocket 16 is fixed at one end (lower end in the figure), and the rotation of the crank shaft (not shown) is transmitted through the timing chain (not shown) stretched between the sprocket 16 and the crank shaft.

[0035] Lubrication of the bearings for supporting both of the cam shafts 11, 12 for rotation and the sliding portions between the three-dimensional cams 13 and the rocker arms 14, is performed by supplying lubricating oil from lubricating oil passages (not shown) formed in the cam shafts 11, 12 to the sliding portions.

[0036] The three-dimensional cam 13, as shown in Figs. 2 and 3, is formed with a cam surface 13a inclined such that its diameter is decreased from one end toward the other end of the cam 13 in the axial direction. The inclined angles of the cam surfaces 13a are set so as to correspond to the inclined angles of the valve stems 5a, 6a of the intake and exhaust valves 5, 6 with respect to the axes of the cam shafts 11, 12. The rocker arm 14 is inclined such that the plane including its rocking axis (axis of a rocker pin described below) crosses at right angles to the plane including the axis of the intake or exhaust valve 5 or 6, though these planes need not necessarily be perpendicular.

[0037] The rocker arm 14 is formed, as shown in Fig. 4, such that a cylindrical boss 17, and an arm 18 protruding in one direction from the boss 17, are molded integrally, and a slipper 19 engaged by the three-dimensional cam 13 of the cam shaft 11 or 12 is fixed to the arm 18. The rocker arm 14 is, as shown in Figs 1 and 2, fitted, at the boss 17, on a columnar rocker pin 20 of a constant diameter, and supported, for rotary movement, on the cylinder head 1 through the rocker pin 20.

[0038] The rocker pins 20, as shown in Fig. 2, are inclined by angle α with respect to the axes of the cam shafts 11, 12 so as to correspond the inclination of the intake and exhaust valves 5, 6 when viewed from the axial direction of the cylinder. The angle α is set at approximately one degree for this embodiment.

[0039] Similarly, the rocker pins 20 are inclined with respect to the axes of the cam shafts 11, 12 when viewed from the direction of the cam shafts 11, 12 (see Fig. 3). The rocker pin 20 for the intake valve 5 and the rocker pin 20 for the exhaust valve 6 on the left-hand side in Fig. 3, and the two rocker pins 20 on the other side, are inclined so as to assume an inverse straddle shape when viewed from the direction of the cam shafts

11, 12. This inclination of the rocker pins 20 allows the rocker arms 14 to rock along the stroking direction of the intake and exhaust valves 5, 6, so that the intake and exhaust valves 5, 6 can be disposed without unreasonable bending load.

[0040] These rocker pins 20 are fixed to the cylinder head 1 using rocker pin holder 21, as shown in Fig. 2. This rocker pin holder 21 is formed so as to extend in the axial direction of the cam shafts 11, 12 between the cam shafts 11, 12 and fixed to the cylinder head 1 with fixing bolts 23, with rocker pins 20 fitted in holes formed in four places at both ends. Each rocker pin 20 is formed with a cutout, which engages the fixing bolt 23 to prevent the rocker pin 20 from coming out from the pin hole, when the fixing bolt 23 is screwed in the cylinder head 1.

[0041] The arm 18 of the rocker arm 14 is formed, at the tip, with an integral pushing projection 18a. for engaging an end cap 24 attached to the valve stem end of the intake or exhaust valve 5 or 6, as shown in Fig. 1, and on the opposite side (upper side in Fig. 1) of the arm 18 from the pushing projection 18a is mounted fixedly the slipper 19. The slipper 19 is formed in the shape with a quadratic surface such that it is convexed on the cam shaft side and extends in the axial direction of the cam shafts 11, 12. Specifically, the sliding surface 19a of the slipper 19 is formed in the shape of a convex such that it is curved out toward the cam when viewed from the axial direction of the rocker pin 20, as shown in Fig. 4(b), and flattened when viewed from the direction perpendicular to the axis of the rocker pin 20, as shown in Fig. 4(c).

[0042] In this embodiment, the length and the mounting position of the rocker arm 14, and the mounting position of the cam shaft 11 or 12 are set such that the distance R1 (see Fig. 1) from the contact point between the pushing projection 18a and the end cap 24 to the rotation center (axial center of the rocker pin 20) is larger when at least the base circle of the three-dimensional cam 13 is in contact with the slipper, than the distance R2 from the rotation center to the contact point between the slipper 19 and the three-dimensional cam 13.

[0043] A pin hole 25 in which the rocker pin 20 is fitted at the boss 17 of the rocker arm 14 is configured, as shown in Fig. 5, such that the inside diameter is constant from one end to the other end in the axial direction. Also, the rocker arm 14 is formed with a plurality of projections 26 on the axial end face of the boss 17, as shown in Fig. 4. These projections 26 are formed so as to be in contact with the end face of the center projection 21 of the cylinder head 1 and the end face of the rocker pin holder 22.

[0044] In the valve drive system 7 described above, rotation of the cam shaft 11 or 12 causes the rocker arm 14 to rotate as shown in Fig. 5. That is, as shown in Fig. 5 by the double dot and dash lines, sliding engagement of the base circle 13b of the three-dimensional cam 13 with the slipper 19 causes the rocker arm 14 to be located at a position where the intake or exhaust valve is closed (position on the upper side of the figure), and sliding engagement of the top 13c of the three-dimensional cam 13 with the slipper 19 causes the rocker arm 14 to be located at a position where the intake or exhaust valve is opened (position on the lower side of the figure). The position at which the cam surface 13a of the three-dimensional cam 13 is in contact with the sliding surface 19a of the slipper 19, moves such that its locus draws an arc on the sliding surface 19a from one end A to the other end B in the axial direction of the rocker pin 20 (see Fig. 6).

[0045] Now, a method of making the three-dimensional cam 13 will be described. The cam surface 13a of the three-dimensional cam 13 is formed using a grindstone 31 as shown in Fig. 7. The grindstone 31 is a disk type with outer circumferential surface 31a extending parallel to its axial direction. In this embodiment, the radius of curvature (radius of the grindstone 31) of the outer circumferential surface 31a is approximately equal to that of the sliding surface 19a of the slipper 19. The radius of curvature of the sliding surface 19a of the slipper 19 herein referred to is the radius of curvature of the sliding surface 19a viewed from the axial direction of the rocker pin 20.

[0046] To grind the cam surface 13a, the cam shaft 11 or 12 provided with cam stocks 32 is first mounted, at one end, to a rotational drive support member 42 of a grinding apparatus 41. The rotational drive support member 42 is adapted to rotate slowly about the axis of the cam shaft 11 or 12 with the cam shaft 11 or 12 supported thereon. After the cam shaft 11 or 12 is thus mounted to the rotational drive support member 42, the journal 11a or 12a of the cam shaft 11 or 12 is supported on a holder shown by numeral 43 in the figure. The holder 43, as shown in Fig. 11(b), is formed with a recess 44 for receiving, in sliding relation, approximately half the circumference of the journal 11a or 12 a, and supported by a frame of the grinding apparatus through brackets (not shown).

[0047] Next, as shown in Fig. 11(a) and Fig. 7, the grindstone 31 is mounted to the grinding apparatus 41 with its axis inclined with respect to the axis of the cam stock 32. The grindstone 31 is disposed on the opposite side from the holder 43 with the cam shaft 11 or 12 therebetween so that the load can be received by the holder 43 during grinding. The cam stock 32 to be ground is the cam stock 32 that is located between the rotational drive support member 42 and the holder 43. In Fig. 7, the axis of the cam stock 32 is shown by the single dot and dash lines C1, and the axis of the grindstone 31 by the single dot and dash lines C2. Angles at which the axis C2 of the grindstone 31 is inclined with respect to the axis C1 of the cam stock 32, are designated by symbols θ1, θ2. The angle θ1 represents an angle at which the axis of the grindstone 31 is inclined with respect to the cam stock 32 in the vertical direction of Fig. 7, and the angle θ2 an angle at which the axis of the grindstone 31 is inclined with respect to the cam stock 32 in the horizontal direction of Fig. 7. The angles θ1, θ2 coincide with the angles which the axis of the rocker pin 20 and that of the cam shaft 11 or 12 make.

[0048] After mounting the cam shaft 11 or 12 and the grindstone 31 to the grinding apparatus 41, the grindstone 31 is rotated at high speed, and the cam surface 13a of the cam stock 32 is ground by the outer circumferential surface 31a of the grindstone 31. At this time, the cam shaft 11 or 12 is rotated at low speed such that the grinding position of the cam stock 32 is changed slowly, and the grindstone 31 is parallel-translated so as to correspond to the cam profile when the amount of grinding reaches a certain predetermined value. The locus of the grindstone 31 when the grindstone 31 moves with respect to the cam stock 32, is shown in Fig. 8.

[0049] When the base circle 13b of the three-dimensional cam 13 is ground, the grinding position, as shown in Fig. 9 by the double dot and dash lines, is determined by parallel-translating the grindstone 31 in a direction of engagement/disengagement with respect to the cam stock 32. When the top 13c of the three-dimensional cam 13 is ground, the grinding position, as shown in Fig. 9 by the solid lines, is determined in addition to the foregoing parallel translation, by parallel-translating the grindstone 31 in a direction perpendicular to the foregoing direction of engagement/disengagement and to the axis of the grindstone 31.

[0050] In this embodiment, the position of the grindstone 31 with respect to the three-dimensional cam 13 during grinding is changed such that it follows the same moving locus as the slipper 19 of the rocker arm 14 driven by the three-dimensional cam 13. This moving locus refers to the locus through which the arc center of the arcuate sliding surface 19 moves.

[0051] As a result of the cam surface 13a being ground by the grindstone 31, the grindstone 31 moves so as to imitate the state of contact between the cam surface 13a and the slipper 19 of the rocker arm 14, to form the cam surface 13c. When the top 13c of the three-dimensional cam 13 is ground, the ground line which appears at the contact portion (ground portion) between the top 13c and the grindstone 31 is arcuate, as shown in Fig. 9 by the broken lines L. The ground line L is approximately the same shape as the contact line (arcuate curve shown in Fig. 6 by the double dot and dash line) which appears when the cam surface 13a engages the slipper 19. As a result of the ground line L being arcuate, a concave 33 is formed at the top 13c of the three-dimensional cam 13, as shown in Fig. 10. The concave 33 is formed in the shape of an arcuate cross-section curved inward at the axially central portion of the three-dimensional cam 13 from other portions.

[0052] With respect to the concavity, there is to say that according to one example the average of the round is just about 1 μm and it is 0 to max. 9 μm on the contacting line with the cam surface and the cam follower surface. On the other hand, the concavity of the cam surface is from 0 to 3 μm on the plane passing through the axis of the cam shaft. Therefore, only Fig. 10 shows the concave surface 33.

[0053] In respect of the axis of rotation of the grindstone, the location of the axis can move continuously and relatively along the trace of the cam follower moving according to one embodiment of the invention, i.e. wherein the position of the grindstone with respect to the three-dimensional cam during grinding is changed such that it follows the same locus as a cam follower drivable by the three-dimensional cam.

[0054] It has been found that as a result of the concave 33 being formed in the cam surface 13a as described above, this concave 33, and the sliding surface 19a can be brought into line contact, so that the oil film of lubricating oil can be retained reliably between the cam surface 13a and the sliding surface 19a. It is believed that this is because these contact portions deform so as to assume the same cross-sectional shape to each other through elastic deformation under the condition that the slipper 19 is pressed against the three-dimensional cam 13 by the elastic force of the valve spring.

[0055] That is, the sliding surface 19a of the slipper 19 constituted by a convex, and the concave 33 of the three-dimensional cam 13, deform so as to correspond with each other in their radii of curvature, thereby effecting a state of line contact. The state of line contact is maintained even if the rocker arm 14 moves in a direction (axial direction of the valve stem 5a or 6a of the intake or exhaust valve 5 or 6) inclined with respect to the direction of deformation of the cam surface 13a.

[0056] Therefore, in the valve drive system with a three-dimensional cam 13 formed using this method of making, radial type intake and exhaust valves 5, 6 can be driven by the three-dimensional cam 13 with improved lubricating ability. As a result, the number of the rocker arms can be reduced using the three-dimensional cams 13, compared with the conventional valve drive system for engines.

[0057] In addition, the concave 33 is formed at the top 13c where the radius of curvature of the cam surface 13a is smaller, that is, the portion where surface pressure is relatively high, and lubricating ability of the top 13c is improved, so that a three-dimensional cam 13 can be manufactured which is not likely to develop partial wear.

[0058] Further, since in this embodiment, a grindstone having a radius of curvature of the outer circumferential surface 31a approximately equal to that of the sliding surface 19a of the slipper 19, is employed as the grindstone 31 used for grinding the three-dimensional cam 13, the radius of curvature of the concave 33 of the three-dimensional cam 13 is likely to coincide with that of the sliding surface 19a of the slipper 19, so that the state of contact between the three-dimensional cam 13 and the slipper 19 comes to be in line contact easily.

Thus, the cam surface 13a and the sliding surface 19a can be brought into line contact with each other at any cam angle at any times.

[0059] Furthermore, in this embodiment, the cam shaft 11 or 12 is supported, at one end, on the rotational drive support member 42 of the grinding apparatus 41, and the cam is ground, with one of journals 11a or 12a on the side of the other end of the cam shaft from the three-dimensional cam 13 to be ground, supported by the holder 43, so that the three-dimensional cam 13 can be ground while supported at both sides thereof in the axial direction. Therefore, in spite of the fact that a plurality of three-dimensional cams 13 and journals 11a or 12a are provided on one cam shaft 11 or 12 and thus the entire length of the cam shaft 11 or 12 is relatively long, vibration of the cam shaft 11 or 12 due to load during grinding can be prevented, so that accurate three-dimensional cams 13 can be formed.

A second embodiment

[0060] An example will be described in detail with reference to Fig. 12, in which the three-dimensional cam 13 is ground using a grindstone with a small diameter. Fig. 12 is an illustration of an embodiment in which grinding is performed using a grindstone with a small diameter, and in the figure, like or equivalent parts as shown in Figs. 1-11 are designated by like reference numerals, omitting detailed descriptions.

[0061] In Fig. 12, numeral 51 designates a grindstone used for this embodiment. The radius of curvature of the grindstone 51 is smaller than that of the sliding surface 19a of the slipper 19.

[0062] To grind the three-dimensional cam 13 using the grindstone 51, the grindstone 51 is parallel-translated so as to follow the ground line L which appears when the three-dimensional cam 13 is ground using the foregoing grindstone 31. Parallel translation, like the first embodiment, has two directions, one of which is a direction of engagement/disengagement of the grindstone 51 and the cam stock 32 and the other of which is a direction perpendicular to the direction of engagement/disengagement and to the axis of the grindstone 51. Other conditions during grinding, that is, the inclination angle of the axis of the grindstone 51, and the support structure of the cam shaft 11 or 12 are the same as in the first embodiment.

[0063] A three-dimensional cam 13 can be also be made by the grinding work using such a small-sized grindstone 51.

[0064] Although, in the first and second embodiments, examples have been shown in which a concave 33 is formed at the top 13c of the three-dimensional cam 13, the concave 33 may be formed throughout the entire cam surface 13a.

[0065] Further, although, in the first and second embodiment, the grindstone 31 or 51 is parallel-translated with respect to the cam shaft 11 or 12 during grinding, on the contrary the cam shaft 11 or 12 may be parallel-translated with respect to the grindstone 31 or 51, or both of the cam shaft 11 or 12 and the grindstone 31 or 51 may be parallel-translated.

[0066] Moreover, the cam shaft manufactured by the method of making a three-dimensional cam for a valve drive system for engines according to this invention, may be used in a lifter type valve drive system. When a three-dimensional cam for the lifter type valve drive system is formed using the method of making according to this invention, grinding is performed such that the ground line L appearing in grinding the cam surface 13a with the grindstone 31 or 51, is a straight line. This is because the lifter, unlike the rocker arm, moves in a direction parallel to the axis of the intake or exhaust valve. The lifter is preferably formed with a sliding surface, engaged with the cam surface 13a, having a convex curved out toward the cam shaft.

[0067] In the three-dimensional cam device according to this invention as described above, as a result of the convex of the cam surface engaging the sliding surface of the cam follower constituted by a convex, the state of contact comes to be in line contact. This state of line contact is maintained even if the cam follower moves in a direction inclined with respect to the direction of displacement of the cam surface.

[0068] Therefore, the oil film of lubricating oil can be retained between the cam surface and the sliding surface of the cam follower, thereby providing a three-dimensional cam device of high durability.

[0069] According to an embodiment of the invention, the state of contact of a portion at the top of the cam where surface pressure is relatively high, can be turned to be in line contact, so that a three-dimensional cam device of higher durability can be manufactured.

[0070] According to another embodiment of the invention, radial type intake and exhaust valves can be driven by the three-dimensional cams with improved lubricating ability. Therefore, the number of the rocker arms can be reduced using the three-dimensional cams, compared with the conventional valve drive system for engines, thereby effecting cost reduction and smaller size.

[0071] According to a further embodiment of the invention, any portion of the cam surface can be formed with a concave curved inward at the axially central portion of the three-dimensional cam from other portions, so that the concave can be easily formed, for example, only at the top of the three-dimensional cam.

[0072] According to a still further embodiment of the invention, the cam surface can be formed in imitation of the cam follower being engaged with the cam surface, so that the cam surface can be ground such that the state of contact with the sliding surface of the cam follower is in line contact throughout the entire cam surface. Therefore, a three-dimensional cam can be made in which the oil film of lubricating oil can be retained reliably between the cam surface and the sliding surface.

[0073] According to other embodiments of the invention, the radius of curvature of the concave of the three-dimensional cam is likely to coincide with that of the sliding surface of the cam follower, and the three-dimensional cam and the cam follower can be brought into line contact with each other at any cam angle at all times, thereby providing higher lubricating ability.

[0074] According to another embodiment of the invention, the three-dimensional cam can be ground while supported at both sides thereof in the axial direction, therefore in spite of the fact that a plurality of three-dimensional cams 13 and journals 11a or 12a are provided on one cam shaft 11 or 12 and thus the entire length of the cam shaft 11 or 12 is relatively long, vibration of the cam shaft 11 or 12 due to load during grinding can be prevented. Thus, accurate three-dimensional cams can be formed.

Claims

1. A three-dimensional cam device having a cam follower (14) adapted to rock in a direction inclined with respect to the direction of displacement of a cam surface (13a) of a three-dimensional cam (13), **characterized in that** the sliding surface (19a) of the cam follower (14) is in the form of a convex of an arcuate cross-section when viewed from the axial direction of a rocker shaft (20), and at least a part of the cam surface (13a) is formed with a concave surface (33) such that the axially central portion of a three-dimensional cam (13) is curved inward from other portions.

2. The three-dimensional cam device according to claim 1, **characterized in that** the part having the concave surface (33) is a portion (13c) of the cam surface (13a) with a smaller radius of curvature.

3. The three-dimensional cam device according to claim 1 or 2, **characterized in that** the entire cam surface (13a) is provided with the concave surface (33).

4. The three-dimensional cam device according to at least one of the preceding claims 1 to 3, **characterized in that** the three-dimensional cam (13) is formed with a cam surface (13a) inclined such that its diameter is decreasing from one end forward to the other end in axial direction of the cam (13).

5. The three-dimensional cam device according to at least one of the preceding claims 1 to 4, **characterized in that** a sliding surface (19a) of the cam follower (14) is formed in the shape of a convex such that it is curved toward the cam (13) when viewed from the axial direction of the pivot axis (20) of the cam follower (14), and flattened when viewed from the direction perpendicular to the pivot axis (20).

6. Use of a three-dimensional cam device according to at least one of the preceding claims for a valve drive system of an internal combustion engine, wherein a plurality of intake and exhaust valves (5,6) are disposed radially in a cylinder.

7. Use of a three-dimensional cam device according to claim 6, **characterized in that** the valve drive system is of a lifter type or that rocker arms (14) are supported on a cylinder head (1) for rocking movement constitute the cam followers.

8. A method of making a three-dimensional cam (13) for a valve drive system for engines in which the outer circumferential surface (13a) of a three-dimensional cam (13) is ground by the outer circumferential surface (31a) of a grindstone (31;51), with the axis (C2) of the grindstone (31;51) being inclined with respect to the axis (C1) of the three-dimensional cam (13), **characterized in that** a cam shaft (11,12) is rotated at relatively low speed during grinding, and at least one of the grindstone (31;51) and the three-dimensional cam (13) is parallel-translated in a direction of engagement/disengagement of said components, and in a direction perpendicular to said direction of engagement/disengagement and to the axis (C2) of the grindstone (31;51), to determine the position of the grindstone (31;51) with respect to the three-dimensional cam (13) during grinding.

9. Method of making a three-dimensional cam for a valve drive system for engines according to claim 8, **characterized in that** both the grindstone (31;51) and the three-dimensional cam (13) are parallel-translated in the direction of engagement/disengagement.

10. Method of making a three-dimensional cam for a valve drive system for engines according to claim 8 or 9, **characterized in that** the position of the grindstone (31:51) with respect to the three-dimensional cam (13) during grinding is changed such that it follows the same locus as a cam follower (14) drivable by the three-dimensional cam (13).

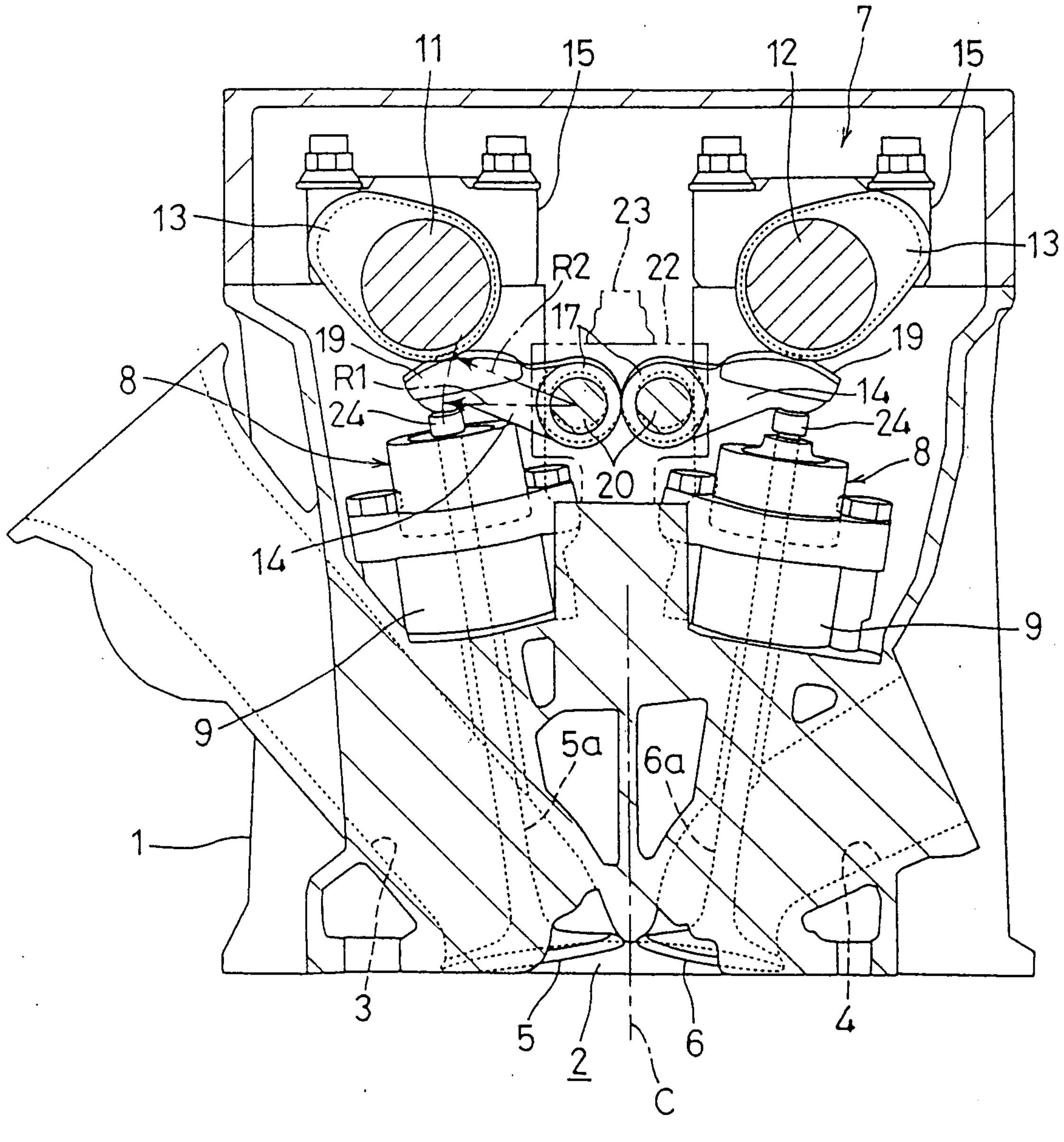
11. Method of making a three-dimensional cam for a valve drive system for engines according to at least one of the preceding claims 8 to 10, **characterized in that** the grindstone (31) being used has approximately the same radius as the radius of curvature of the sliding surface (19a) of the cam follower (14).

12. Method of making a three-dimensional cam for a valve drive system for engines according to at least one of the preceding claims 8 to 10, **characterized in that** the grindstone (51) being used has a radius smaller than the radius of curvature of the sliding surface (19a) of the cam follower (14), and the position of the grindstone (51) with respect to the three-dimensional cam (13) during grinding is changed such that it follows a ground line (L) which appears when the cam surface (13a) is ground by a grindstone (31) with a radius nearly equal to the radius of curvature of the sliding surface (19a) of the cam follower (14).

13. Method of making a three-dimensional cam for a valve drive system for engines according to at least one of the preceding claims 8 to 12, **characterized in that** a cam shaft (11,12) is used which is formed with a plurality of three-dimensional cams (13) and bearing journals (11a,12a) respectively spaced axially, and the three-dimensional cam (13) is ground, with one end of the cam shaft (11,12) supported on a rotational drive support member (42) of a grinding apparatus (41), and with one of said journals (11a,12a) at the side of the other end of the cam shaft (11,12) from the three-dimensional cam (13) to be ground, supported by a holder (43) of the grinding apparatus (41).

14. Method of making a three-dimensional cam for a valve drive system for engines according to at least one of the preceding claims 9 to 13, **characterized in that** the grindstone (31;51) is rotated at relatively high speed.

[FIG. 1]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12
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22
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R2
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19
19
R1
14
8
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9
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5a
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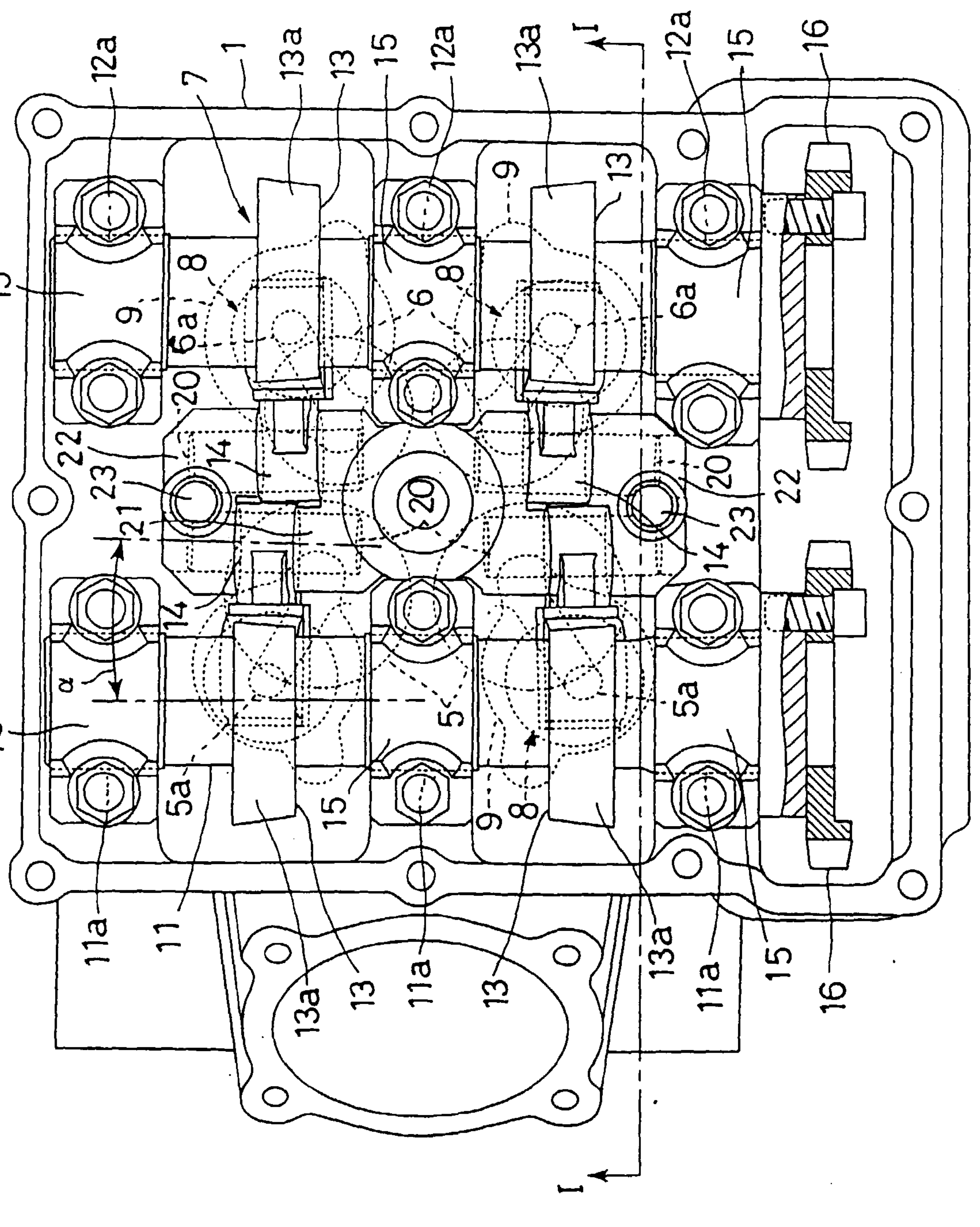
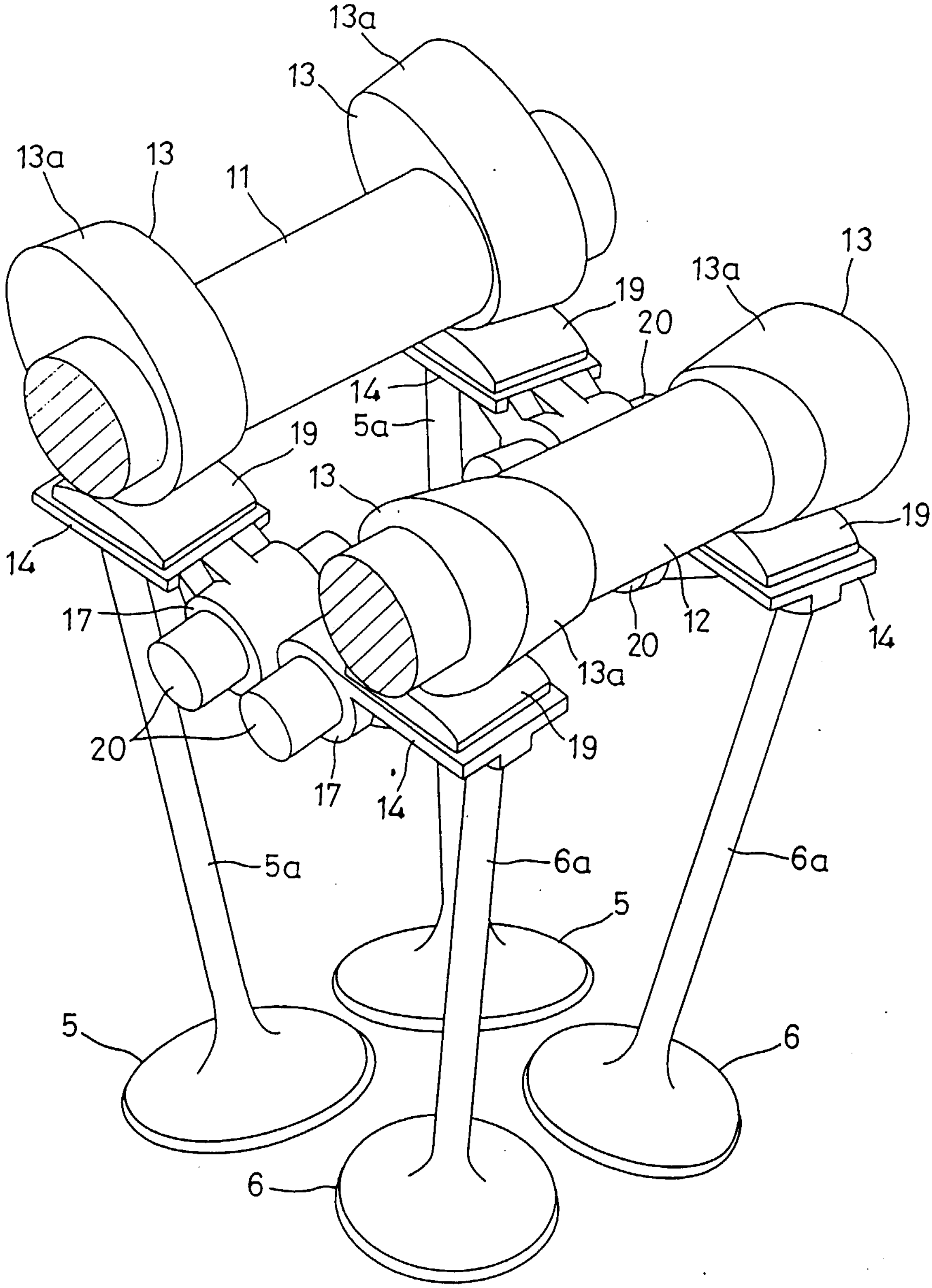
6
4
C

[FIG. 2]



[FIG. 3]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19
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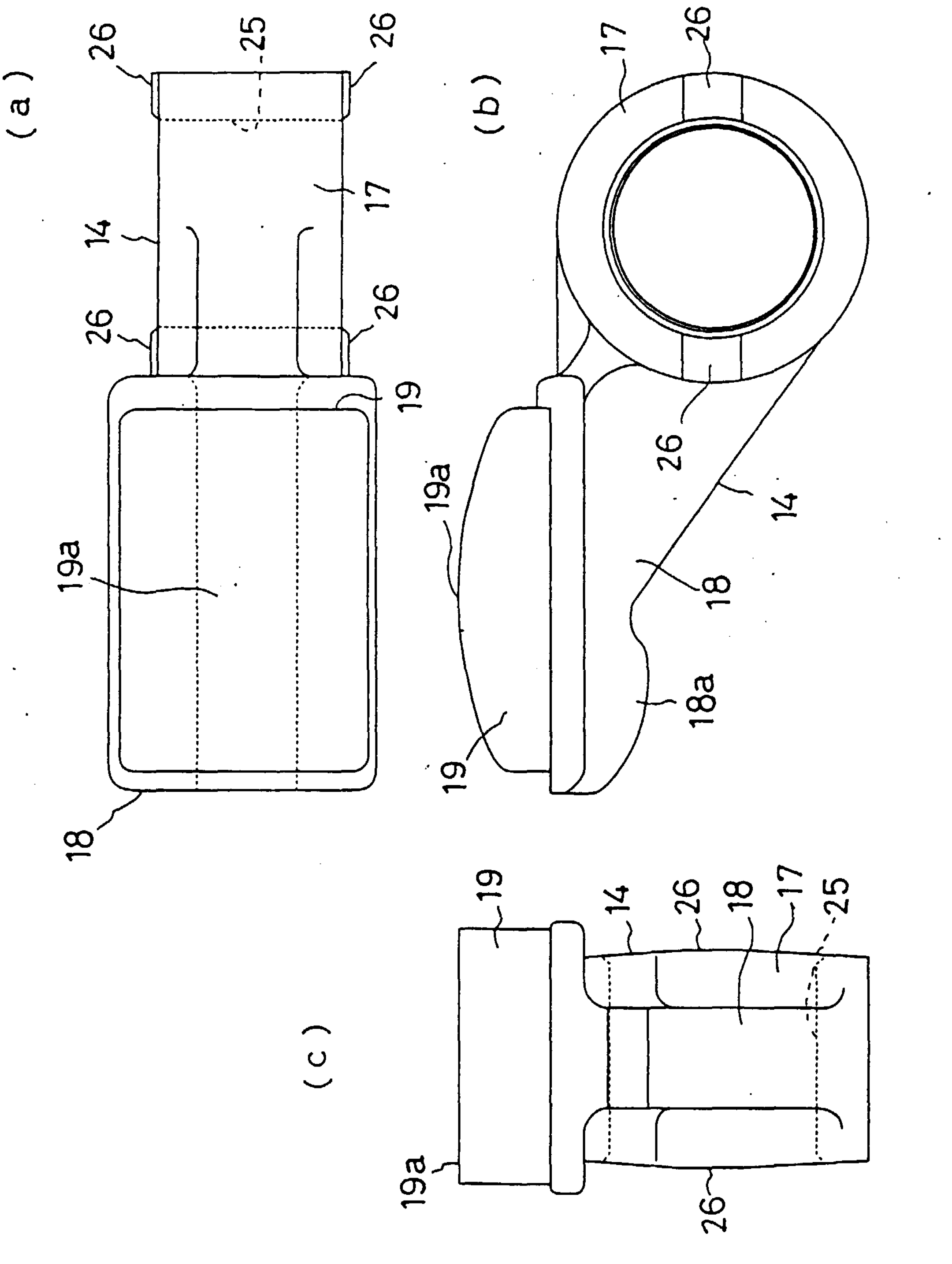
5
6
6

[FIG. 4]


(a)
26
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14
17
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19a
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(b)
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14
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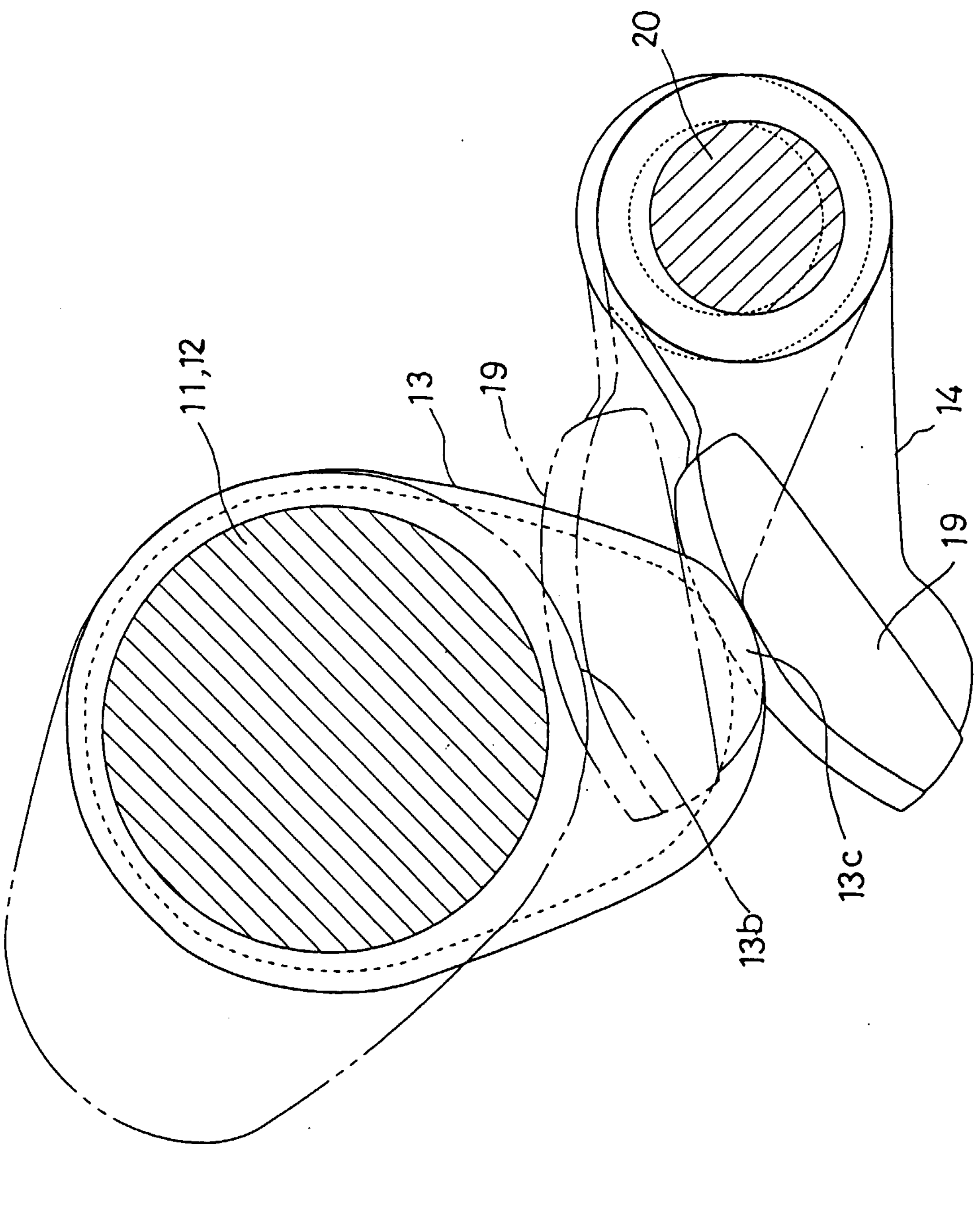
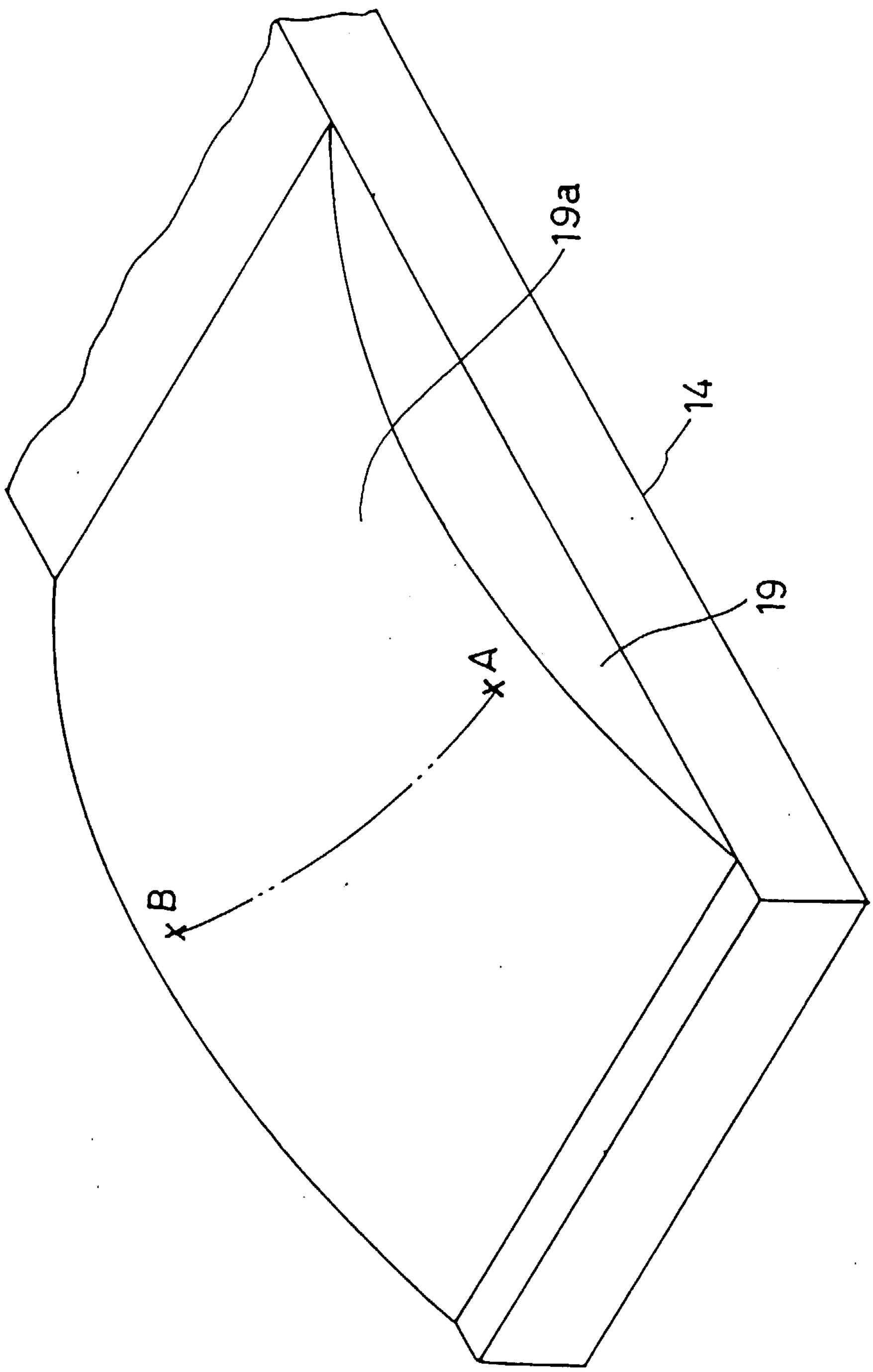
18a
19
(c)
19
14
26
18
17
25
19a
26

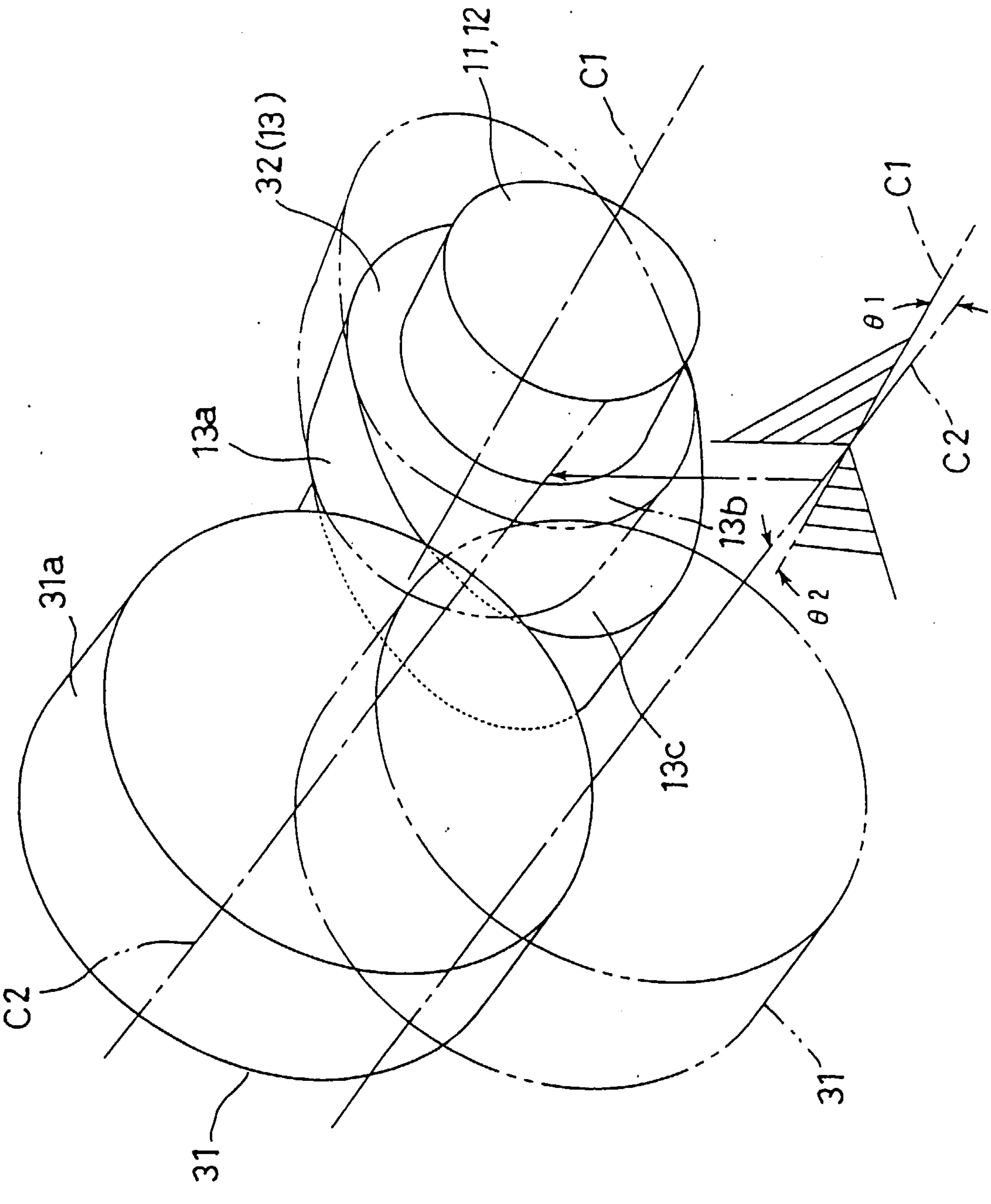
[FIG. 5]



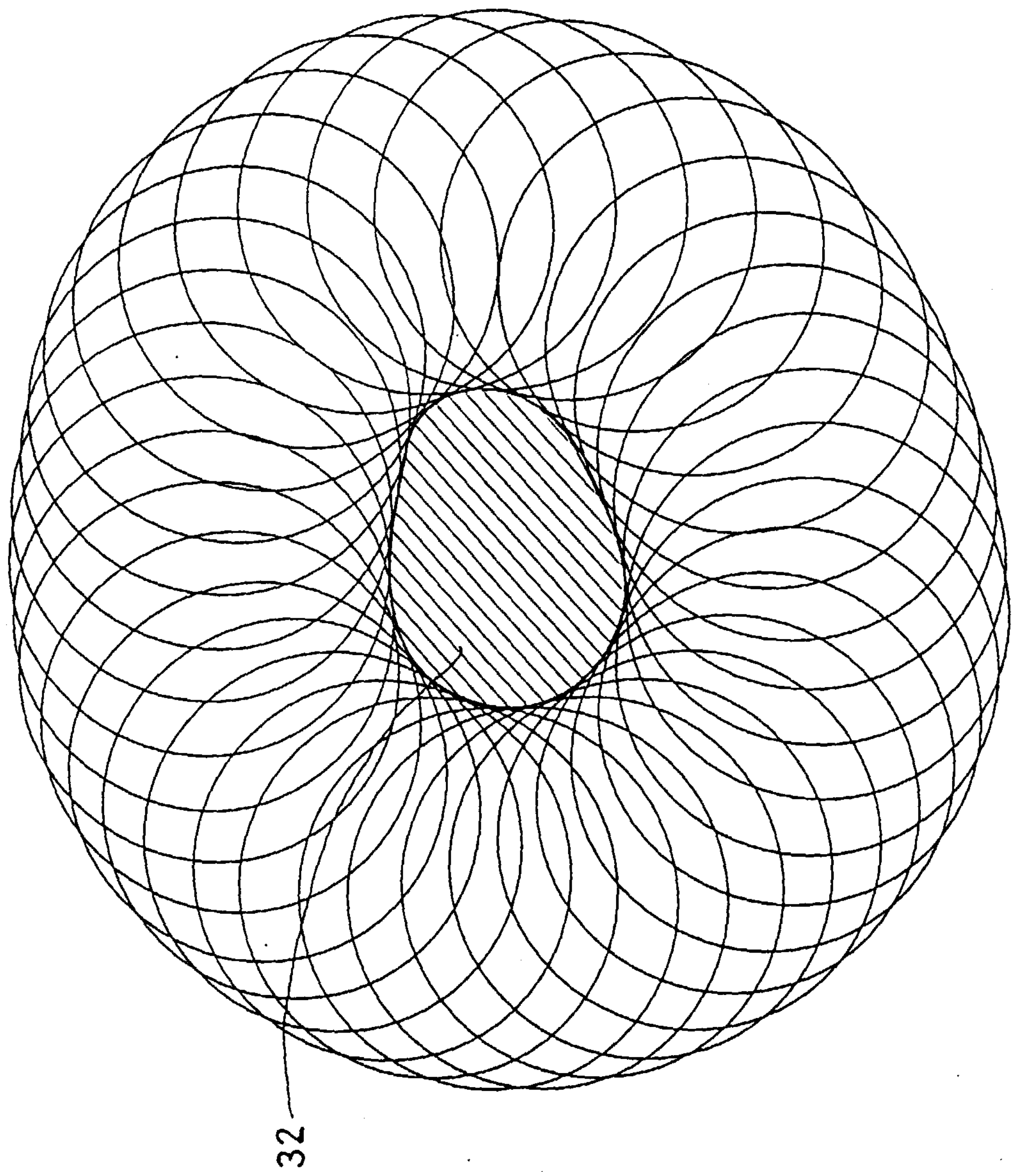
[FIG. 6]



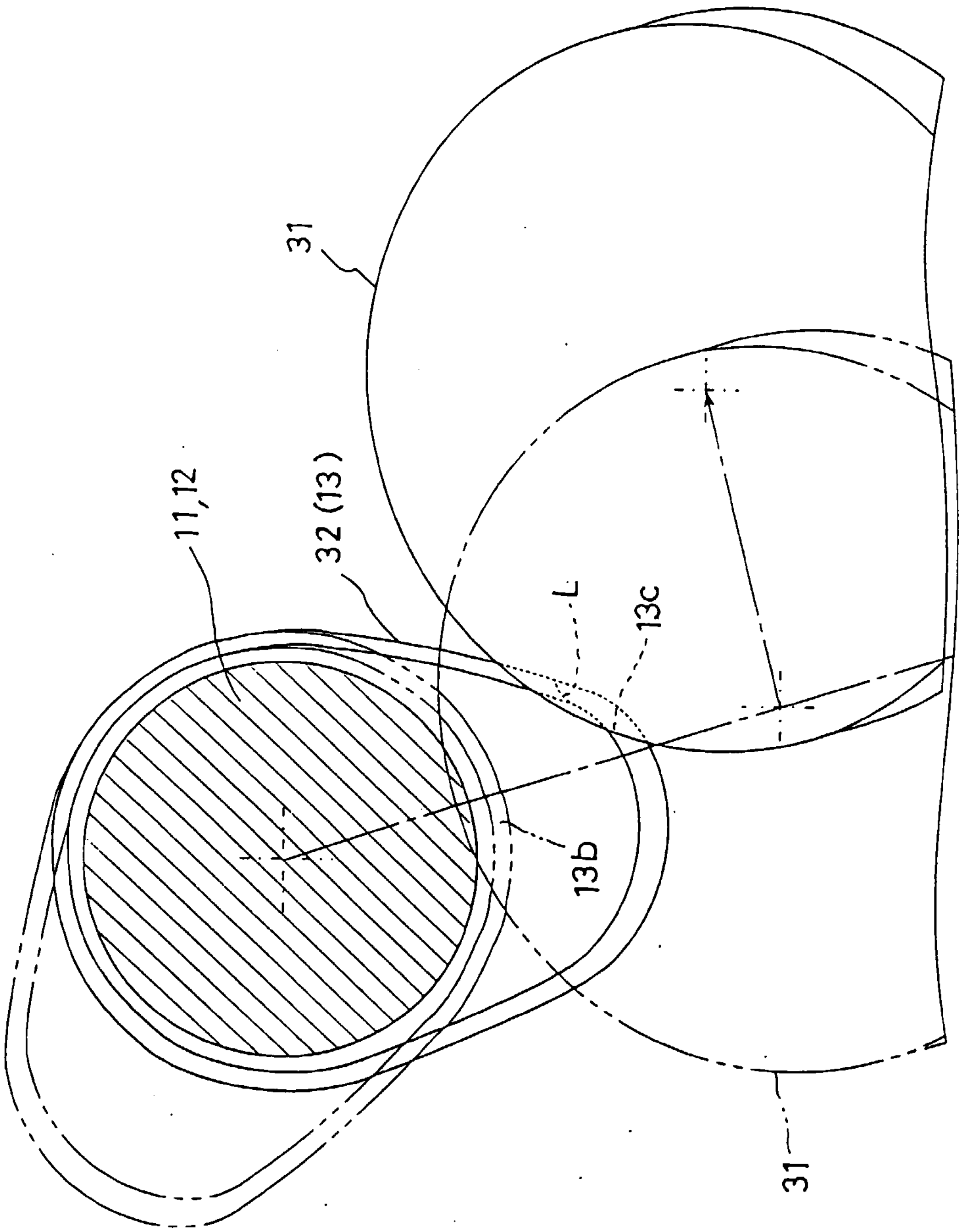
[FIG. 7]



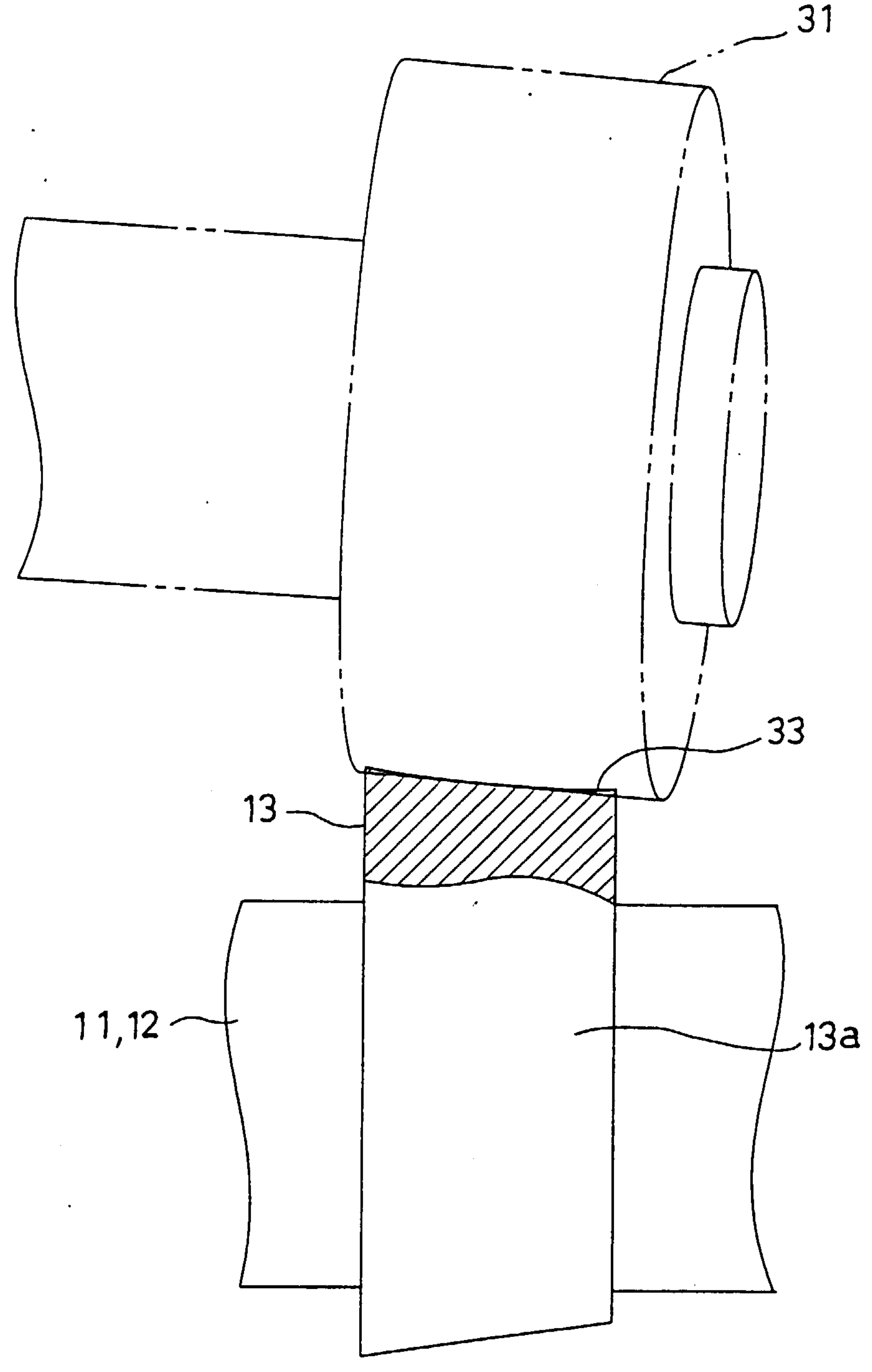
[FIG. 8]



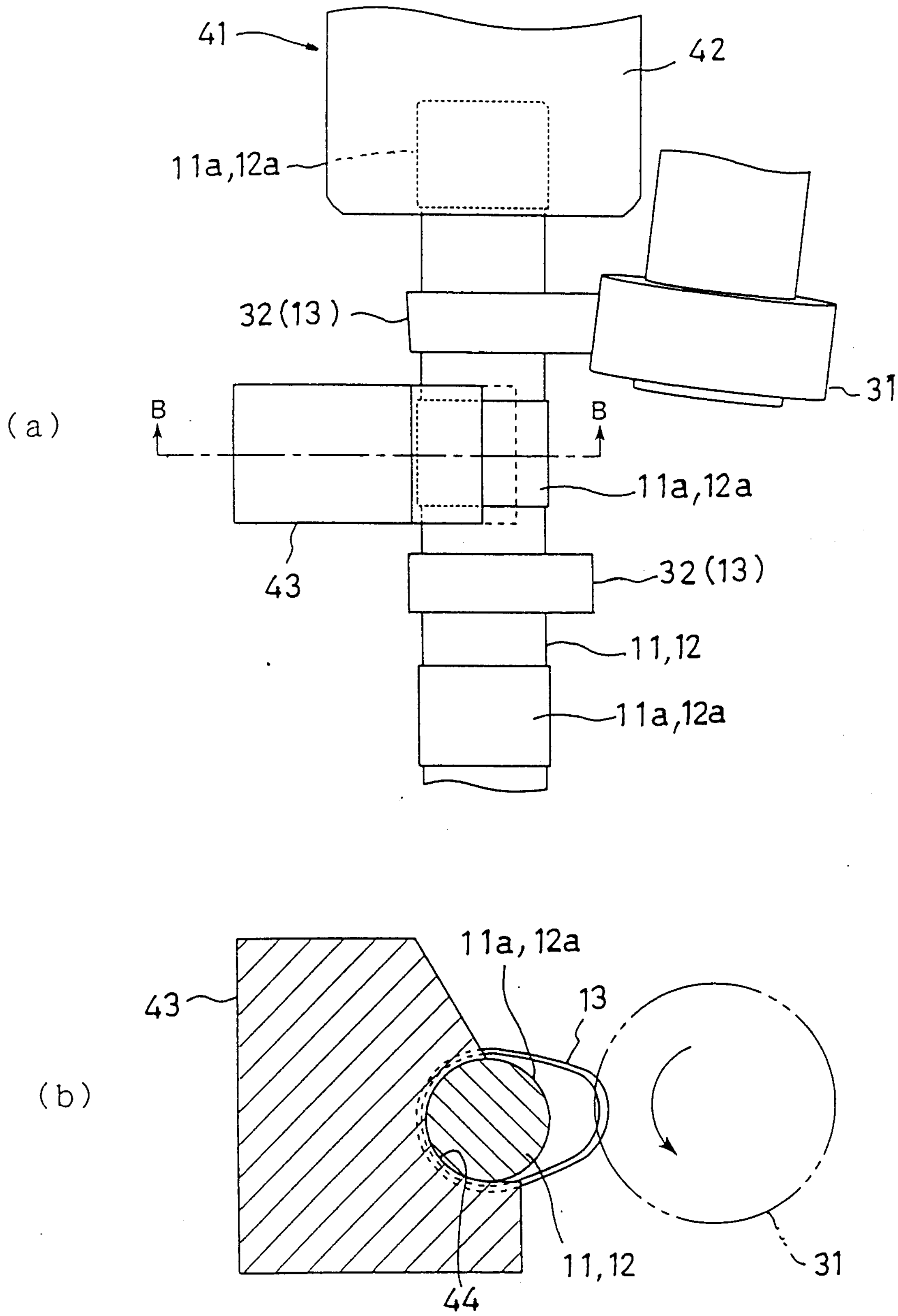
[FIG. 9]



[FIG. 10]



[FIG. 11]


(a)
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42
11a,12a
32(13)
31
B
B
11a,12a
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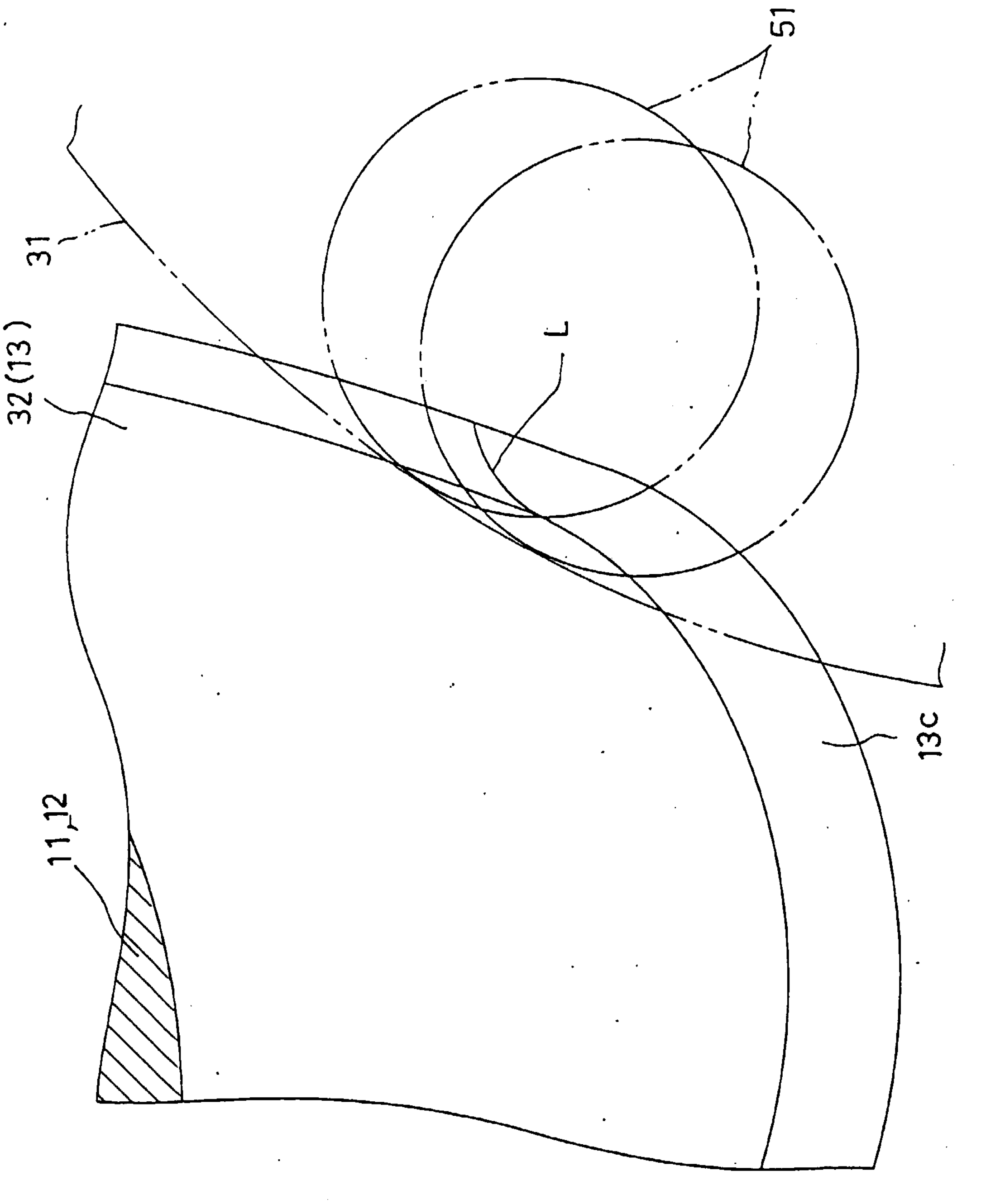
32(13)
11,12
11a,12a
(b)
11a, 12a
43
13
11,12
31
44

[FIG. 12]



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 11 9451

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 3 618 573 A (TRW INC) 9 November 1971 (1971-11-09) * the whole document * ---	1,5,8	F01L1/26 F01L13/00 F01L1/08
A	DE 34 44 901 A (AUDI AG) 12 June 1986 (1986-06-12) * page 6-7; claim 3; figures 1,2 * ---	1,3,4	
A	EP 0 930 421 A (AUDI AG) 21 July 1999 (1999-07-21) * abstract; figures * ---	1,6	
A	PATENT ABSTRACTS OF JAPAN vol. 1999, no. 11, 30 September 1999 (1999-09-30) & JP 11 165248 A (TOYOTA MOTOR CORP), 22 June 1999 (1999-06-22) * abstract * -----	1,8	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
			F01L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	18 January 2000	Klinger, T

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