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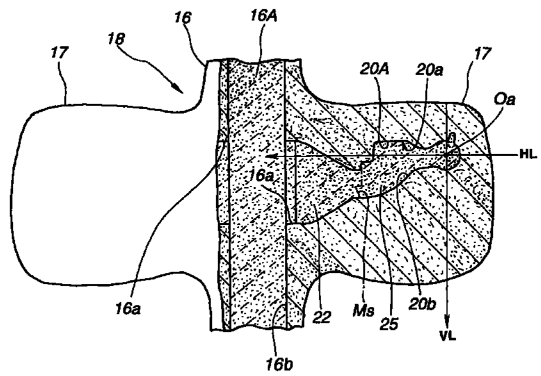
(54) Method and mould for investment casting of engine rocker arms

(57) An engine rocker arm is produced after machining a cast part that has been obtained after grinding stubs off casting. To prevent shrinkage cavity from existing in cast parts, investment casting uses a mold including a plurality of mold parts. Each mold part includes a runner portion and a mold cavity. The position of the mold cavity relative to the runner ensures flow of splash of molten metal down to the runner.

FIG.2



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Description

FIELD OF THE INVENTION

The present invention relates to a method and apparatus for investment casting for production of engine rocker arms.

BACKGROUND OF THE INVENTION

In a method and apparatus for investment casting, a master pattern is produced (producing a master pattern). The pattern is a replica of a desired product and made of easily worked material. From the master pattern, a master die is produced (producing a master die from the master pattern). Steel dies may be machined directly with the help of a computer CAD/CAM. Patterns are made by pouring molten wax into the master die, or injecting it under pressure, and allowing it to harden (producing wax patterns). The individual wax patterns are attached to a central sprue and runners by means of heated tools and melted wax (assembling the wax patterns onto a common wax sprue). The result of this step is a pattern cluster or tree. The cluster is dipped into ceramic slurry (coating the cluster with a thin layer of investment material). Refractory grain is sifted onto the cluster (producing the final investment around the coasted cluster). The dipping step and grain-sitting step are repeated several times to obtain desired shell. After investment or mold material around the cluster has set and dried (allowing the investment to harden), the wax patterns are melted out of mold (melting the wax pattern to remove it from mold). Because the wax "disappeared," the process was called the lost-wax process, and the name is still used occasionally. The mold is heated. Heating to sufficiently high temperatures ensures complete removal of the mold wax, cures the mold to give added strength, and allows the molten metal to retain its heat and flow more readily to all thin sections (preheating the mold in preparation for pouring). The mold is filled with molten metal by gravity (pouring the molten metal). Various methods, beyond simple pouring, can be used to ensure complete filling of the mold. Among these methods are the use of positive air pressure, evacuation of the air from the mold, and a centrifugal process. The mold is broken away from the castings (removing the castings from the mold). Castings are removed from the sprue, and gate stubs ground off.

Shrinkage cavity in cast parts is shortcoming that occurs in investment casting. Parts with shrinkage cavity are less strong, less aesthetic, and in many cases require additional finishing. Parts with many shrinkage cavities are not usable at all.

The present invention aims at improving method and apparatus for investment casting for producing a cast part, which is used as an engine rocker arm, such that shrinkage cavity in the cast part is zero or negligibly small in number and in size.

Figures 10 and 11 are top plan and side views of a cast part according to known investment casting, which is used as a rocker arm (called the sub-rocker arm) in a known variable valve actuation (VVA) apparatus according to U.S. Patent No. 5,297,516, issued on Mar. 29, 1994. The rocker arm, generally designated by the reference numeral 2, includes a base end portion 2A where a through hole 2a for receiving a rocker shaft is formed by drilling. Extending from the base end portion is an arm portion 2B. On its upper surface, this arm portion 2B has a part-cylindrically protruded cam follower 2b adapted to cooperate with a cam of a camshaft. The arm portion 2B has a dependent portion extending downwardly, viewing in Figure 11 to a lower flat end surface 2D. The dependent portion is recessed inwardly from its front edge to define a shoulder 2S and an inclined ramp 2C connecting continuously with the shoulder 2S.

It would be desired to employ investment casting for production of the rocker arm. If the position of each of wax patterns relative to a common wax sprue is inappropriate, then, in the step of pouring molten metal, splash of the molten metal remains in a portion of mold cavity, causing occurrence of shrinkage cavity in the casting. As shown in Figures 10 and 11, such shrinkage cavity Vo may occur within a region VA, which includes axial end walls and the outer peripheral wall of the base end portion 2A, of the rocker arm 2. In this case, the base end portion 2A is less strong, shortening life of the VVA apparatus. Usually shrinkage cavities occur in the perimeter portion of the casting. Finishing allowance may be increased to allow additional finishing. Considering yield, this measure cannot be taken.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to prevent shrinkage cavity, which occurs in investment casting, from existing in cast parts that are used for rocker arms, thereby to avoid poor yield.

According to one aspect of the present invention, there is provided an apparatus for investment casting for production of rocker arms, comprising:

a mold including a runner and a mold cavity for forming a cast part that makes a rocker arm with a base end portion,
wherein the position of said mold cavity relative to said runner ensures flow of splash of molten metal to said runner.

According to another aspect of the present invention, there is provided a method for investment casting for production of rocker arms each having a base end portion formed with a through hole for receiving a rocker shaft, comprising the steps of:

producing a master pattern that is a replica of a desired rocker arm with a base end portion;
producing a master die from said master pattern;
producing wax patterns by pouring molten wax into said master die;
attaching the individual wax patterns to a central sprue and runners to produce a pattern cluster;
coating said pattern cluster with investment material to obtain a desired shell around said pattern cluster;
melting said wax pattern out of said shell to obtain a mold including a trunk and mold parts attached to said trunk;
filling said mold with molten metal;
removing castings out of said mold by breaking away said mold;
removing said castings from said sprue;
grinding off gate stubs to obtains cast parts;
machining said cast parts to make the desired rocker arm;
wherein each of said mold parts include a runner and a mold cavity and the position of said mold cavity relative to said runner ensures flow of splash of molten metal to said runner.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic view of a portion of a mold for investment casting, with a wax pattern attached to a central common wax sprue of a pattern cluster, illustrating a preferred implementation of the present invention.
Figure 2 is a similar view to Figure 1 illustrating a comparative example of a mold for investment casting.
Figure 3 is a top plan view of a VVA apparatus used to test a rocker arm produced by investment casting using the mold of Figure 1 and a rocker arm produced by investment casting using the mold of Figure 2.
Figure 4 is a section taken through the line 4-4 of Figure 3 with a camshaft.
Figure 5 illustrates result of endurance test of comparative example of rocker arm by investment casing using the mold of Figure 2.
Figure 6 is a different view of the test result shown in Figure 5.
Figure 7 illustrated cracking occurred in test specimen - used in fatigue test.
Figure 8 is a different view of the test result shown in Figure 7.
Figure 9 graphs the fatigue strength corresponding to different sizes of cavity.
Figure 10 is a top plan view of a rocker arm produced according to the conventional investment casting.
Figure 11 is a side view of the rocker arm shown in Figure 10.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figure 1, a portion of a mold 10 for investment casting is shown. Also shown is a pattern cluster resulting from attaching wax pattern pieces, only one being shown, to a central common wax sprue 16A. The wax pattern pieces are produced alter pouring molten wax into a master die, not shown. A separating line Ms divides each wax pattern piece into a replica 24 of a rocker arm 26 (see Figures 3 and 4) and a runner 14. The cluster is surrounded by shell. The shell includes a central common trunk 16 around the sprue 16A and a plurality of mold parts, only two being shown at 17, 17, around the wax pattern pieces, respectively. The wax is melted out of the mold 10, leaving cavities, only one being shown at 12, a common central passage 16b, and ports 16a, 16a via which the cavities are open to the central passage 16b. After the wax has been completely removed, the mold 10 is filled with molten metal. This is accomplished by pouring by gravity molten metal into the central common passage 16b. The molten metal enters each of the cavities 12 via the corresponding port 16a. The mold 10 is broken away from the castings. The castings are removed from the sprue, and gate stubs ground off along the separating line Ms. to obtain cast parts. Each of the cast parts requires surface finishing and hole drilling to obtain the desired configuration of rocker arm 26 shown in Figures 3 and 4.

Each mold part 17 is formed with cavity 12 and includes wall means defining the cavity 12. The wall means include mutually spaced end walls and a peripheral wall interconnecting the spaced end walls, The peripheral wall may be divided into an upper peripheral wall portion 12a and a lower peripheral wall portion 12b as viewed in Figure 1. The lower peripheral wall portion 12b defines the contour extending over the upper side of a base end portion 2A of the rocker arm 26, the upper side of the arm portion 28 (viewing in Figure 4), and a cam follower 2b. The upper peripheral wall portion 12a defines the contour extending over the lower side of the base end portion 2A of the rocker arm 26 and the lower flat end surface 20 thereof.

Each of the cavities 12 connects with the adjacent end of the runner 14. The opposite end of the runner 14 defines port 16a communicating with the common central passage 16b. The runner 14 extends in a radial outward direction from a centerline of the common passage 16b.

The upper peripheral wall portion 12a includes a datum plane 12A of the mold cavity 12, which plane 12A defines the lower flat end surface 20 of the rocker arm 26. The datum plane 12A is inclined upward, with respect to the horizontal plane, as the radial distance from the centerline of the common passage 16b increases. Further, the lower peripheral wall 12b of the cavity 12 is inclined upward, with respect to the horizontal plane, as the radial distance from the centerline of the common passage 16b increases. In this embodiment, the upward inclined datum plane 12A forms a predetermined angle a (alpha) of around 20 degrees with respect to the horizontal plane. In Figure 1, the reference character VL indicates a vertical line drawn through a point Oa, which corresponds to the center of a through hole 26a drilled through the base end portion 2A. The vertical line VL is parallel to the centerline of the common passage 16a. The reference character HL indicates a horizontal line intersecting at right angles the vertical line at the point Oa. The datum plane 12A extends in parallel to a sloping line SL. The line SL is drawn through the point Qa. Deviation of a point on line SL from line HL decreases as radial distance from the centerline of passage 16b decreases as long as this point belongs to a set of points on line SL, which are less distant from the centerline than the point Oa is. The line SL forms the predetermined angle α (alpha) of around 20 degrees with respect to the line HL. Deviation of a point on the lower peripheral wall 12b from line HL decreases as the radial distance from the centerline increases as long as this point belongs to a set of points on the wall 12b, which are less distant from the centerline than the point Oa is.

Carbon tools steel (Japanese Industrial Standard (JIS) symbol SKD 11) was used as material of molten metal. The molten metal with 1700 degrees C is poured into the central common passage 16b at a predetermined flow rate over 10 seconds.

In the step of molten metal pouring, splash of the molten metal may reach the closed end portion of the cavity 12, which closed end results in forming the base end portion 2A of the rocker arm 26. In this case, the splash moves, due to its own weight, down to the runner 14, causing shrinkage cavity to occur there. This portion is finally ground off, resulting in producing a cast part free from shrinkage cavity or at least with reduced, in number and size, shrinkage cavities.

It will be appreciated that the position of the cavity 12 relative to the runner 14, which is characterized by the upward inclined datum plane 12A and the upward inclined lower peripheral wall 12b of the cavity 12 facilitates the flow of splash down to the runner 14.

The inventor has confirmed that some of cast parts have a base end portion free from shrinkage cavity, and the other cast parts have a base end portion formed with a number, less than a predetermined number, of shrinkage cavities, each having a diameter less than 0.5 mm.

Referring to Figures 3 and 4, a variable valve actuation (VVA) apparatus is described. This apparatus was used to conduct an endurance test of rocker arm 26 obtained after finishing the casting from the mold 10 shown in Figure 1. It was also used to conduct another endurance test of rocker arm 26R obtained alter finishing the casting from a comparative example of mold 18 shown in Figure 2.

For the detail description of this VVA apparatus, reference should be made to U.S. Patent No. 5,297,516, which is hereby incorporated in its entirety by reference.

In Figure 3, the reference numeral 32 designates a main rocker shaft that is mounted to a cylinder head of an engine. The main rocker shaft 32, which extends a through hole 30a, pivotally supports a main rocker arm 30. The main rocker arm 30 includes a pair of parallel rails or arms 30A and 30B. The rails 30A and 30B are interconnected and have leading end portions that are designed for abutting contact with stems of the corresponding cylinder valves, respectively.

As readily seen from Figure 4, the main rocker shaft 32 extends in parallel to a camshaft CS that is supported by cam bearings and driven by a motor. The camshaft has a pair of axially spaced low-speed cams CSb and a high-speed cam CSa that is disposed between the axially spaced low-speed cams CSb. The high-speed cam CSa and low-speed cams CSb are formed as integral parts of the camshaft CS, which is made of low-alloy chilled cast iron.

The rails 30A and 30B carry rollers 36A and 36B via bearing shafts 40A and 40B, respectively. For allowing rotational movement of the rollers 36A and 36b, the bearing shafts 40A and 40B support needle bearings, respectively. These rollers 36A and 36B are arranged for contact with the low-speed cams CSb, respectively.

As best seen in Figure 3, the main rocker arm 30 has a pair of spaced support walls 38A and 38B. A sub-rocker shaft 34, which extends through a hole 26a of sub-rocker arm 26, has its opposite ends press fitted into holes of the support walls 38A and 38B. In this manner, the sub-rocker arm 26 is pivotally mounted to the main rocker arm 30 for movement through a space between the two rails 30A and 30B. The sub-rocker arm 26 is formed with a cylindrically protruded cam follower 26b that is arranged for contact with the high-speed cam CSa.

The sub-rocker 26 is formed with a shoulder portion 26S below the cam follower 26b and also with an inclined portion 26C connecting with this shoulder portion 26S. The shoulder portion 26S is arranged for catching an upper end of a lever 40.

At a portion below the shoulder portion 26S, the main rocker arm 30 carries a pin 28 that supports the above-mentioned lever 40. The lever 40 is formed with a hole 40a receiving the pin 28.

The lever 40 has a laterally extending portion 40A from a portion immediately below the upper end. A plunger in the form of a spring retainer, not shown, is received in a cylindrical recess with a return spring, not shown. Owing to the action of the return spring, the spring retainer is in abutting engagement with the laterally extending portion 40A. Thus, the lever 40 is resiliently biased clockwise, viewing in Figure 4.

Viewing in Figure 4, at its lower end, the lever 40 is in abutting engagement with a plunger 50 of a hydraulic driver. With regard to the hydraulic driver, the main rocker arm 30 is recessed inwardly toward the main rocker shaft 32 to define a cylindrical bore 56. This bore 56 receives the plunger 50. The plunger 50 defines in the bore 56 a hydraulic chamber. Drilling through wall separating the hydraulic chamber from the main rocker shalt 32 forms a passage 58. This passage 58 has one end opening to the hydraulic chamber and the opposite end facing the main rocker shalt 32.

The main rocker shaft 32 is hollowed to form an oil gallery 52. This oil gallery 52 extends in the longitudinal direction of the main rocker shalt 32. The main rocker shalt 32 is formed with a port 54 that provides communication between the oil gallery 52 and the passage 58.

As best seen in Figure. 4, at its lower side, the sub-rocker arm 26 is equipped with a lost motion mechanism 46. The lost motion mechanism 46 includes a spring retainer 44 and a lost motion spring 48. The sub-rocker arm 26 is recessed inwardly from its lower surface to form a bore 42 that receives the lost motion mechanism 46. At its one end, the lost motion spring 48 bears against a closed end of the bore 48, and at its opposite end, it bears against the spring retainer 44. At its spherical end, the spring retainer 44 rests on a seat portion formed on the main rocker arm 30.

During first operation mode requesting the low-speed cams CSb to operate the cylinder valves, no hydraulic fluid pressure is applied to the hydraulic chamber behind the plunger 50. In this case, the lever 40 is disengaged from the sub-rocker arm 26 due to the action of the return spring acting on the laterally extending portion 40A. The high-speed cam CSa causes the sub-rocker arm 26 to pivot about the sub-rocker shaft 34. This pivotal motion of the sub-rocker arm 26 is not transmitted to the main rocker arm 30 because of the disengagement of the lever 40 from the shoulder portion 26S.

During second operation mode requesting the high-speed cam CSa to operate the cylinder valves, hydraulic fluid pressure is applied to the hydraulic chamber behind the plunger 50. This causes the lever 40 to rotate counterclockwise viewing in Figure 4 until the shoulder portion 26S of the sub-rocker arm 26 catches the upper end of the lever 40. After the shoulder portion 26S has caught the upper end of the lever 40, the pivotal motion of the sub-rocker arm 26 is transmitted via the lever 40 and the pin 28 to the main rocker arm 30, thus operating the cylinder valves.

First endurance test was conducted in the following manner. A hydraulic pressure is applied to the hydraulic chamber behind the plunger 50 to keep the sub-rocker arm 26 catching at its shoulder portion 26S the upper end of the lever 40 as shown in Figure 4. Speed of the camshaft CS was 3900 rpm. Amount of lift by the sub-rocker arm 26 was 11 mm. Temperature of hydraulic fluid (7.5W-30, SG equivalent oil) was 120 degrees C. The test continued over 500 hours. The rocker arm 26 did not suffer any cracking alter the test.

Second endurance test was conducted under the same condition as the first endurance test except that speed of the camshaft CS was 4000 rpm. The rocker arm 26 did not suffer any cracking after the test.

Referring to Figure 2, the comparative example of a mold 18 for investment casting is shown. Also shown is a pattern cluster resulting from attaching wax pattern pieces to a central common wax sprue 16A. A separating line Ms divides each wax pattern piece into a replica 25 of a rocker arm 26A (see Figures 3 and 4) and a runner 22. The cluster is surrounded by shell. The shell includes a central common trunk 16 around the sprue 16A and a plurality of mold parts, only two being shown at 17, 17, around the wax pattern pieces, respectively. The wax is melted out of the mold 18, leaving mold cavities, only one being shown, a common central passage 16b, and ports 16a, 16a via which the mold cavities are open to the central passage 16b. After the wax has been completely removed, the mold 18 is filled with molten metal. This is accomplished by pouring by gravity molten metal into the central common passage 16b. The molten metal enters each of the mold cavities via the corresponding port 16a. The mold 18 is broken away from the castings. The castings are removed from the sprue, and gate stubs ground off along the separating line Ms to obtain cast parts. Each of the cast parts requires surface finishing and hole drilling to obtain the desired configuration of sub-rocker arm 26R shown in Figures 3 and 4.

Each mold part 17 is formed with mold cavity and includes wall means defining the mold cavity. The wall means include mutually spaced end walls and a peripheral wall interconnecting the spaced end walls. The peripheral wall may be divided into an upper peripheral wall portion 20a and a lower peripheral wall portion 20b as viewed in Figure 2. The lower peripheral wall portion 20b defines the contour extending over the upper side of the base end portion 2A of the rocker arm 26R, the upper side of the arm portion 2B (viewing in Figure 4), and the cam follower 2b. The upper peripheral wall portion 20a defines the contour extending over the lower side of the base end portion 2A of the rocker arm 26R and the lower fiat end surface 2D thereof.

The upper peripheral wall portion 20a includes a datum plane 20A of the mold cavity, which plane 20A defines the lower flat end surface 2D of the rocker arm 26R. The datum plane 20A is parallel to the horizontal plane. As seen from Figure 2, the portion of the lower peripheral wall 20b which defines the upper side of the base end portion 2A forms a well. In Figure 2, the reference character VL indicates a vertical line drawn through a point Oa, which corresponds to the center of the through hole 26a drilled through the base end portion 2A. The vertical line VL is parallel to the centerline of the common passage 16a. The reference character HL indicates a horizontal line intersecting at right angles the vertical line at the point Oa. The datum plane 20A extends in parallel to the horizontal line HL. The portion of the lower peripheral wall 20b which defines the upper side of the base end portion 2A forms a well that is recessed downwards along the vertical line VL.

Carbon tools steel (Japanese Industrial Standard (JIS) symbol SKD 11) was used as material of molten metal. The molten metal with 1700 degrees C is poured into the central common passage 16b of the mold 18 at a predetermined flow rate over 10 seconds.

The inventor confirmed that cast parts obtained after investment casting using the mold 18 suffered from shrinkage cavity. The shrinkage cavity was found in the portion of each of the case parts, which forms the base end portion 2A. The diameter of the cavity was about 1 mm. The rocker arms 26R were produced alter surface finishing and hole drilling the cast parts.

The first and second endurance tests were conducted using the rocker arms 26R. The results of these tests revealed occurrence of cracking where the shrinkage cavity was.

Figures 5 and 6 show the result of the second endurance test of the rocker arm 26R. The reference numeral 60 designates the shrinkage cavity that occurred during investment casting. The reference numeral 60A designates an inner wall defining the shrinkage cavity. Cracking 60B was found, which connects the shrinkage cavity 60 and the through hole 26a surrounded by chamfered inclined surface 26ac.

Fatigue test was conducted to find the limiting stress versus the size of shrinkage cavity. The limiting stress value below which a cast part, formed with shrinkage cavity, does not crack is an important criterion in inspection stage of cast parts.

The test specimens, which are hereinafter denoted by the reference numeral 62, were prepared. Each test specimens, which was a cast part obtained alter investment casting using the mold 10 shown in Figure 1, was surface finished and drilled to form a through hole 62a (see Figures 7 and 8) to make the configuration of the sub-rocker arm 26. As a replica of shrinkage cavity, electric spark machining was used to cut a cylindrical cavity 64 inward toward the through hole 62a (see Figures 7 and 8). The test specimens 62 prepared were formed with cylindrical cavities 64 with different diameters falling in a range up to 1 mm. Each test specimen 62 was installed to replace the sub-rocker arm 26 in the VVA apparatus shown in Figures 3 and 4. In conducting the test, the lever 40 was held in the illustrated position to maintain positive motion connection between the test specimen 62 and the main rocker arm 30. In Figure 4, a jig JG was used to hold the camshaft CS and the main rocker shaft 32. With the camshaft CS held in the illustrated position, the rail portions 30A and 30B of the rocker arm 30 were subjected to repeated loading as indicated by an arrow F in Figure 4. The repeated loading employed in this test was the periodic sinusoidal mode in which a number of loading cycles was 10^7 cycles. The peak stress was increased to a value at which the test specimen 62 cracked as shown in Figures 7 and 8. In Figure 7, the cracking is indicated by the reference numeral 64B. The cracking 64B interconnects the cavity 64 having an inner wall 64A and the through hole 62a surrounded by chamfered inclined surface 62ac.

Figure 9 graphs the results of this fatigue test. Curve La in Figure 9 is stress versus different sizes of shrinkage cavity, or S-D curve La. Any point on this S-D curve La is the fatigue strength corresponding to different sizes of shrinkage cavity. In Figure 9, the required minimum fatigue strength is 10 KN as drawn by a horizontal line. From the S-D curve La, it will be noted that if the size of the cavity is less than 0.7 mm in diameter D, the required minimum fatigue strength is exceeded. Broken line curve Lb is also drawn in Figure 9. Any point on this curve Lb is 90 percent of the fatigue strength plotted on the S-D curve La. From the broken line curve Lb, it will be noted that if the size of the cavity is less than 0.5 mm in diameter D, the required minimum fatigue strength is exceeded.

From the preceding description, it will now be appreciated that production of rocker arms by investment casting without shrinkage cavity and with good yield has been ensured.

Claims

1. An apparatus for investment casting for production of rocker arms, comprising:

    a mold including a runner and a mold cavity for forming a cast part that makes a rocker arm with a base end portion,
    wherein the position of said mold cavity relative to said runner ensures flow of splash of molten metal to said runner.

2. An apparatus as claimed in claim 1, wherein said mold cavity has a portion corresponding to the base end portion of the rocker arm, said portion of said mold cavity is positioned relative to said runner such that splash of molten metal flows out of said portion toward said runner.

3. A method for investment casting for production of rocker arms each having a base end portion formed with a through hole for receiving a rocker shalt, comprising the steps of:

    producing a master pattern that is a replica of a desired rocker arm with a base end portion;
    producing a master die from said master pattern;
    producing wax patterns by pouring molten wax into said master die;
    attaching the individual wax patterns to a central sprue and runners to produce a pattern cluster;
    coating said pattern cluster with investment material to obtain a desired shell around said

pattern cluster;
melting said wax pattern out of said shell to obtain a mold including a trunk and mold parts attached to said trunk;
filling said mold with molten metal;
removing castings out of said mold by breaking away said mold;
removing said castings from said sprue;
grinding off gate stubs to obtains cast parts;
machining said cast parts to make the desired rocker arm;
wherein each of said mold parts include a runner and a mold cavity and the position of said mold cavity relative to said runner ensures flow of splash of molten metal to said runner.

4. A rocker arm produced by the method for investment casting as claimed in claim 3.

5. A rocker arm produced by investment casting comprising a base end portion free from shrinkage cavity that occurred in investment casting.

6. A rocker arm produced by investment casting comprising a base end portion with shrinkage cavity with less than 0.5 mm in diameter, which occurred in investment casting.

FIG.1

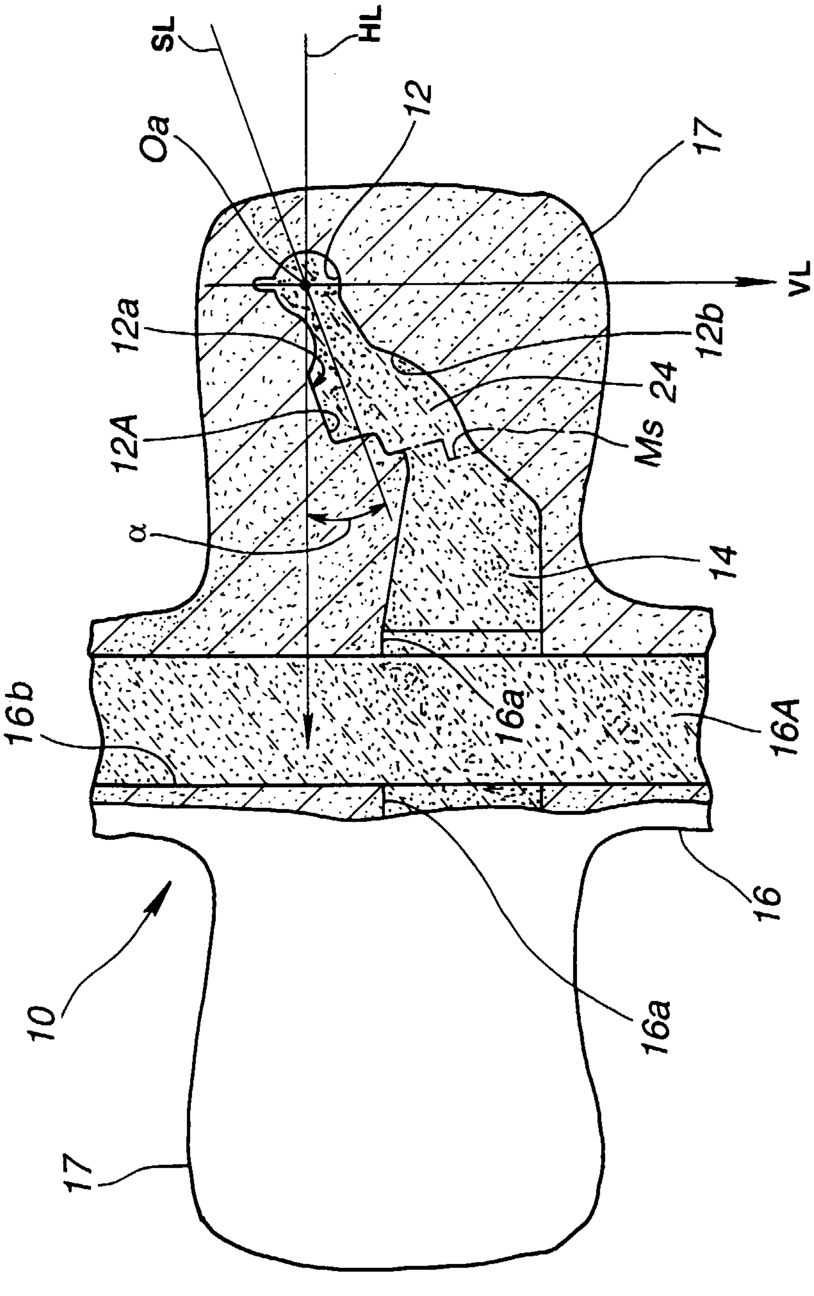


FIG.2

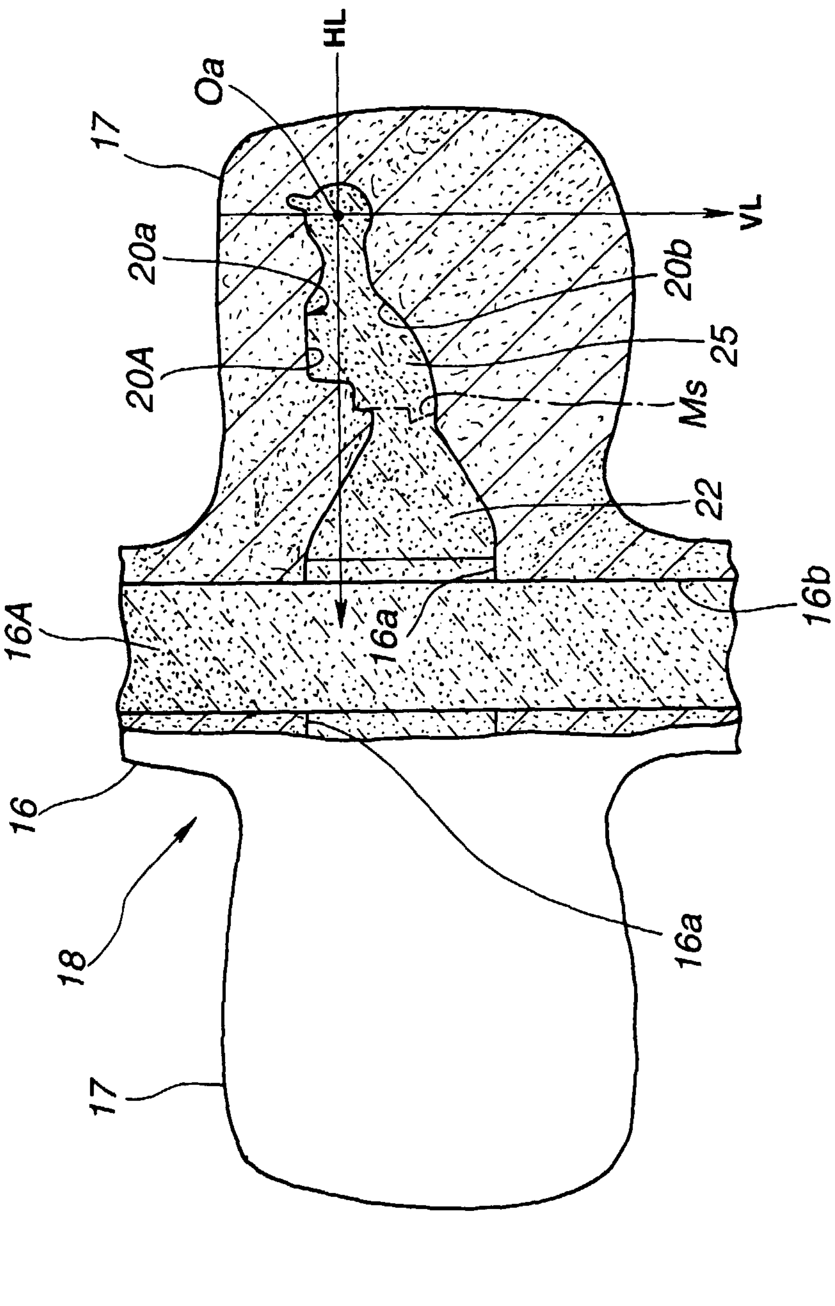


FIG.3

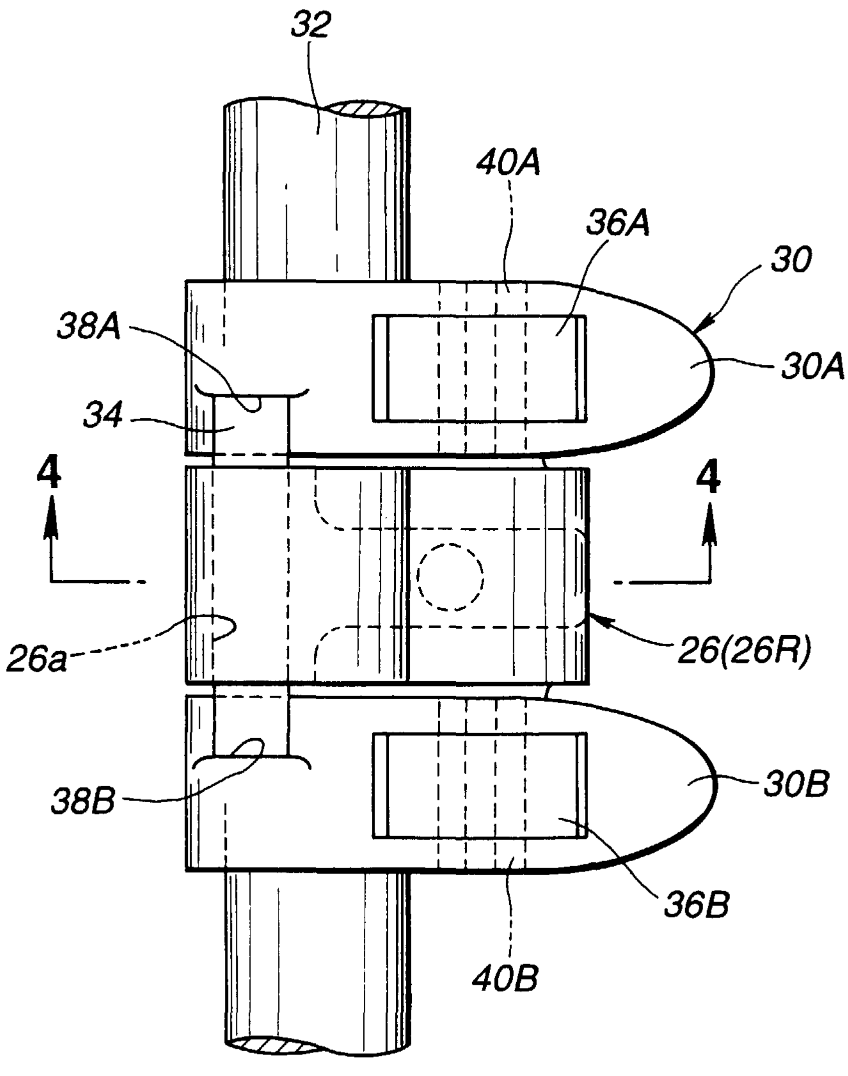
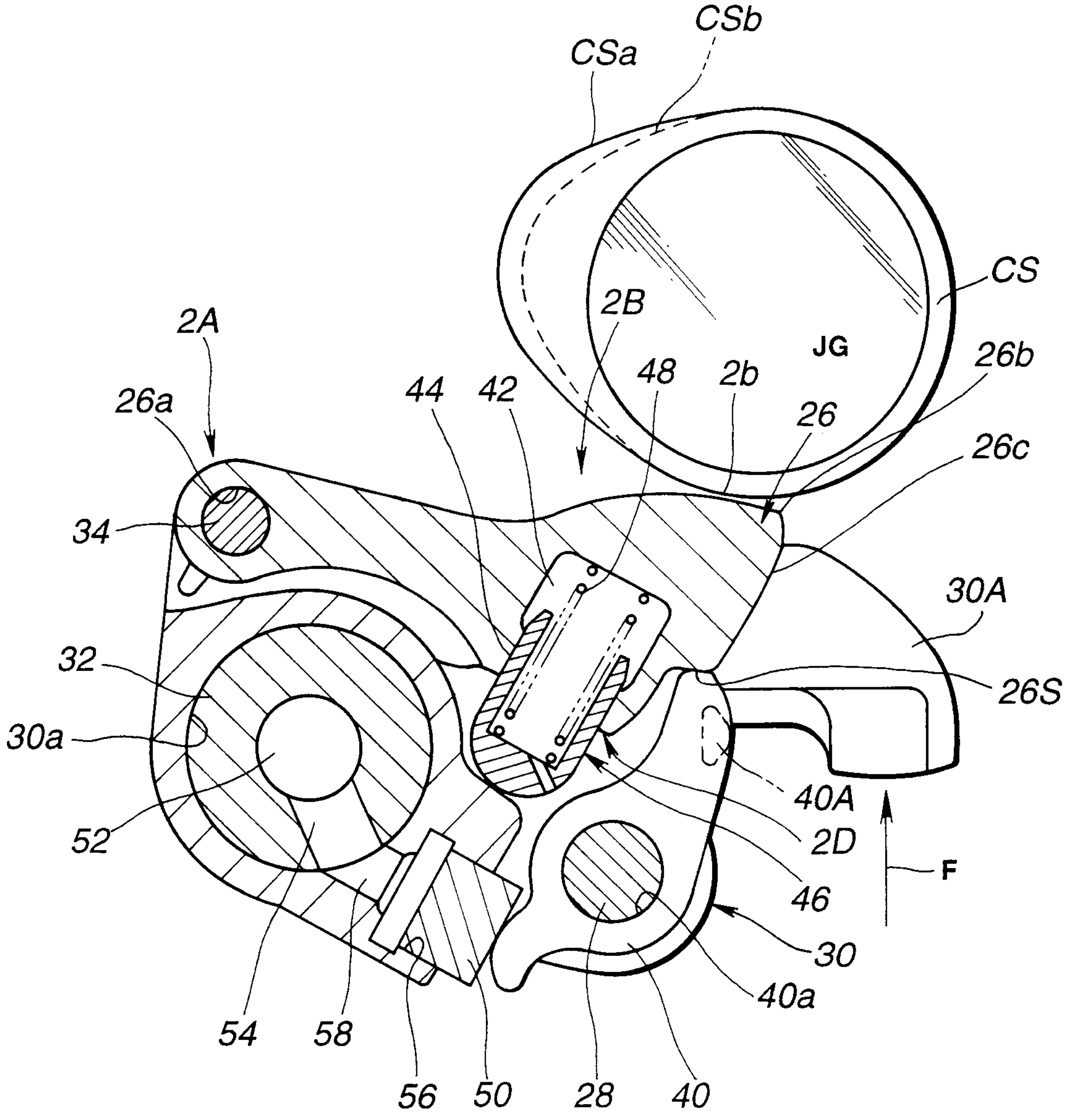


FIG.4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56
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28
40

FIG.5

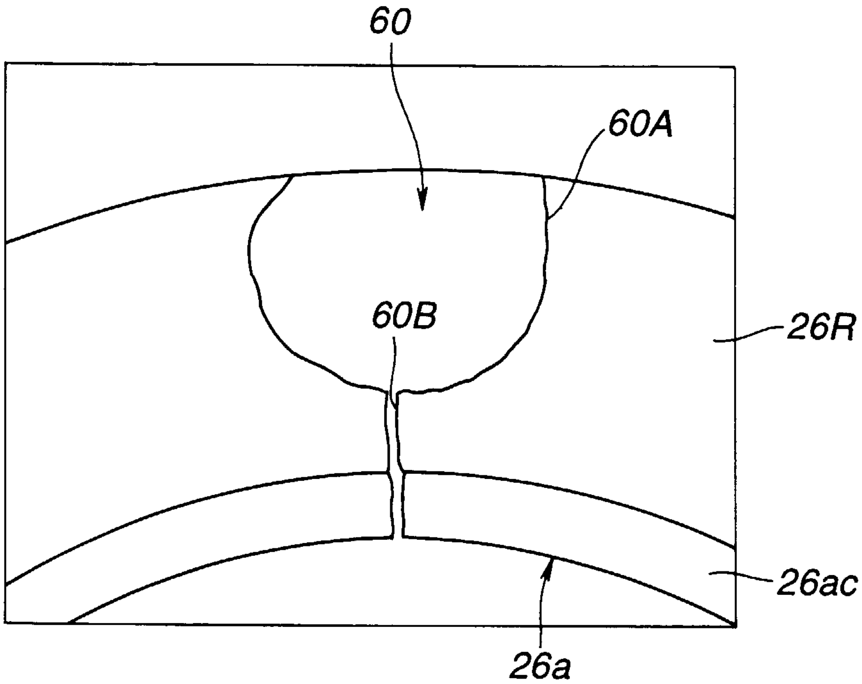


FIG.6

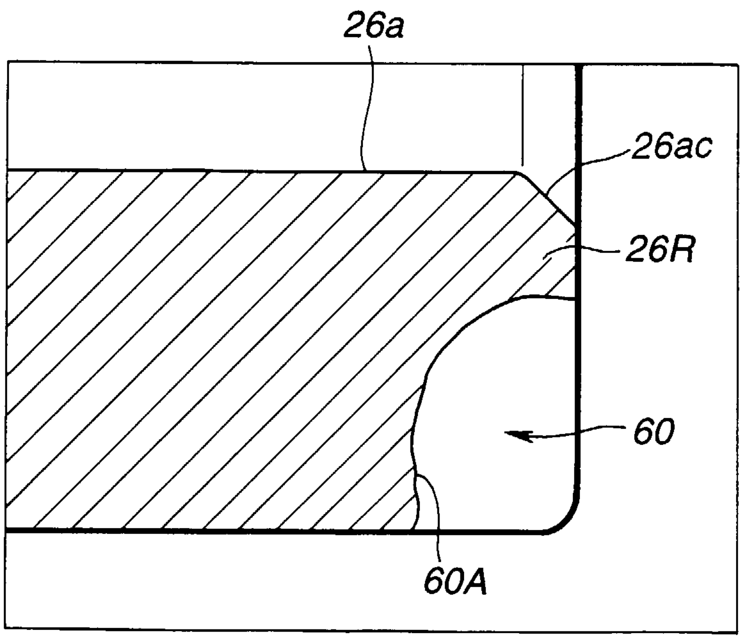


FIG.7

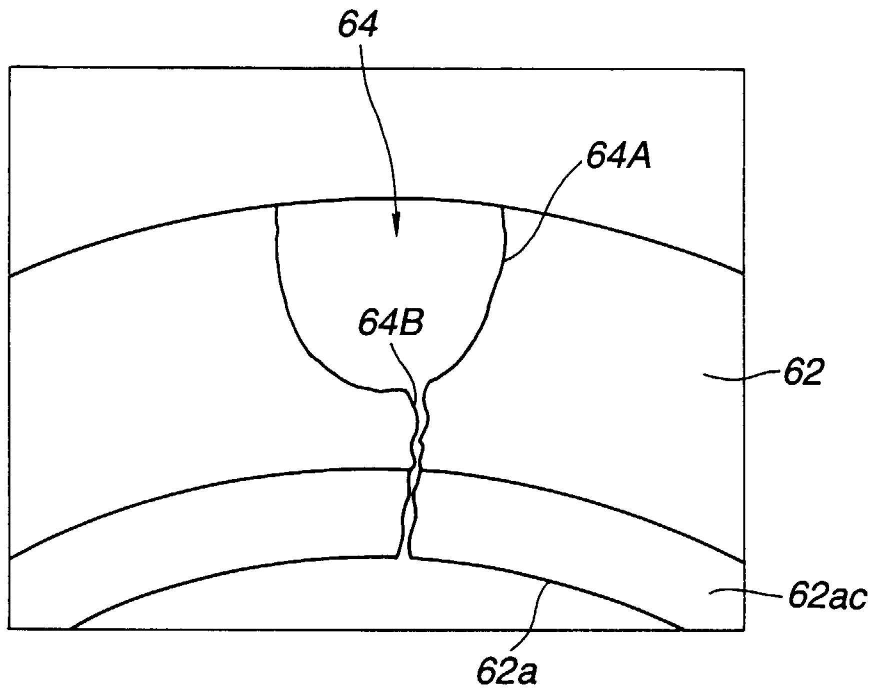


FIG.8

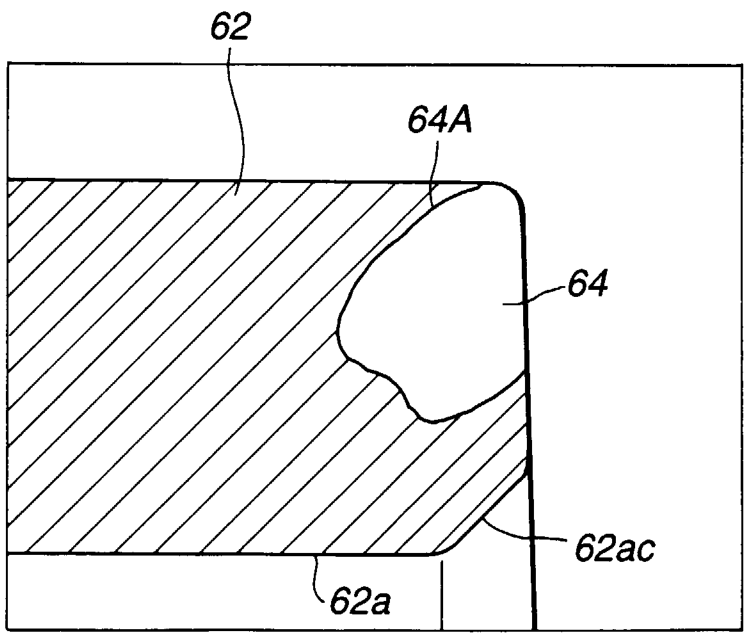


FIG.9

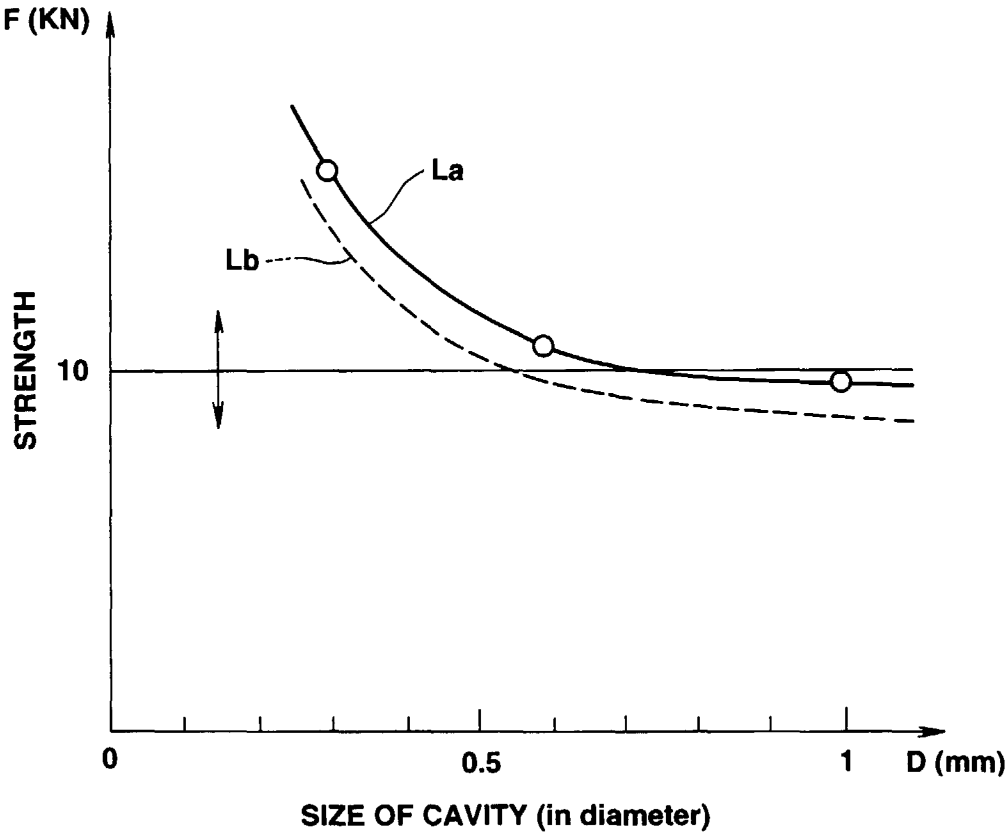


FIG.10
(PRIOR ART)

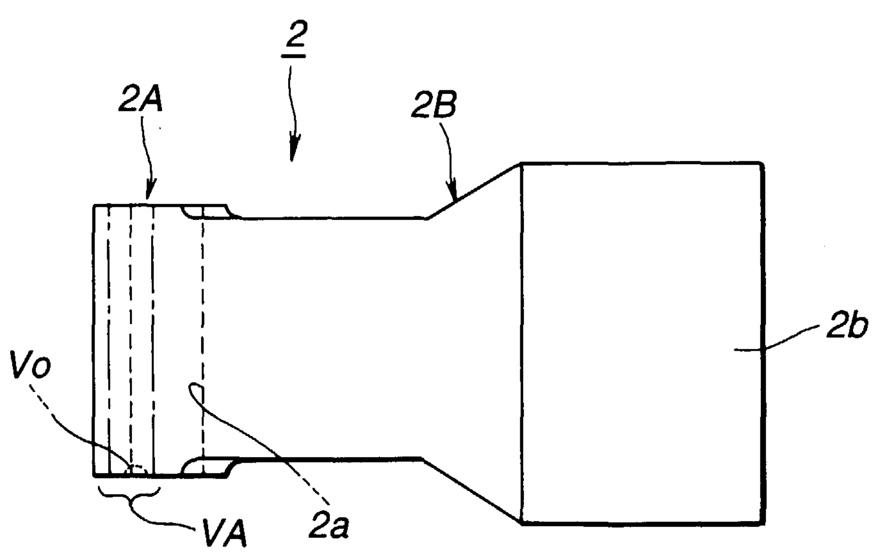
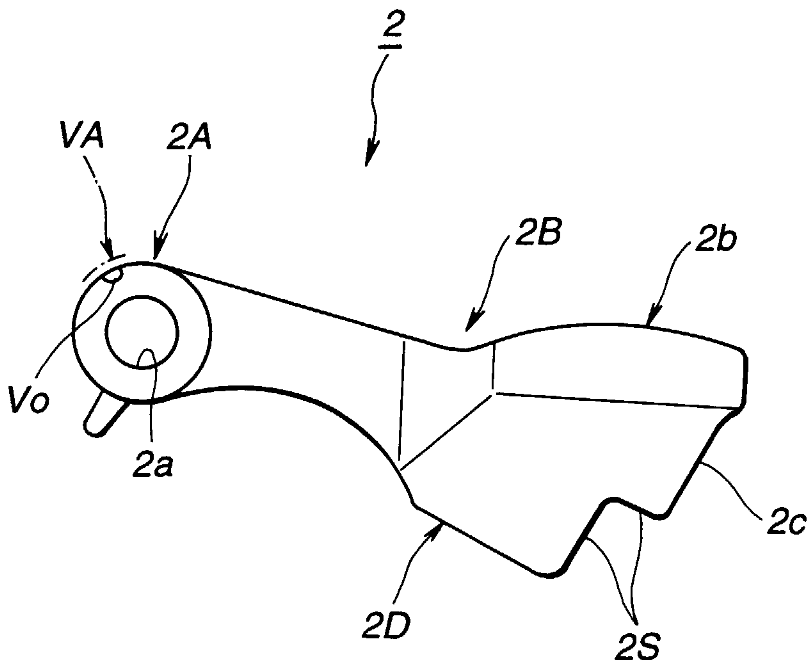


FIG.11
(PRIOR ART)



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 11 2205

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.6)
X	US 5 163 391 A (GREEN KEITH ET AL) 17 November 1992 * figure 1 *	1-6	B22C9/04 B22C9/08
X	US 5 113 924 A (GREEN KEITH ET AL) 19 May 1992 * figure 1 *	1-6	
Y	PATENT ABSTRACTS OF JAPAN vol. 096, no. 004, 30 April 1996 & JP 07 314117 A (DAIDO STEEL CO LTD), 5 December 1995 * abstract *	1-6	
Y	US 4 969 957 A (OHSAKI SHIGEMI ET AL) 13 November 1990 * column 6, line 16 - column 7, line 25 *	1-6	
Y	PATENT ABSTRACTS OF JAPAN vol. 096, no. 007, 31 July 1996 & JP 08 081737 A (DAIDO STEEL CO LTD;UNISIA JECS CORP; NISSAN MOTOR CO LTD), 26 March 1996 * abstract *	1-6	TECHNICAL FIELDS SEARCHED (Int.Cl.6): B22C
D,A	US 5 297 516 A (HARA SEINOSUKE) 29 March 1994 * figure 3 *	1-6	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	6 October 1998	WOUDENBERG, S

CATEGORY OF CITED DOCUMENTS

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