

Description

[0001] This application claims priority to Japanese patent application serial number 2004-277281, the contents of which are incorporated herein by reference.

[0002] The present invention relates to a method for making an elongated product having an enlarged head portion such as an engine valve. The present invention also relates to forging machines used in the method.

[0003] As methods for making an elongated product having an enlarged head portion such as an engine valve, the following is well-known in the art:

(1) Upset forging method: a method in which a round bar stock for upsetting is cut; an enlarged head portion, a so-called "onion", is formed by upsetting with electrical energization and heating of an electrical upsetter; and then a mushroom-shaped valve head is formed by hot upsetting the enlarged head portion.

(2) Hot extrusion forging method: a method in which a round bar stock is cut; the stock is heated by induction heating; a stem portion with an onion is formed by hot extrusion; and a valve head is formed by hot upsetting.

(3) Total cold forging method: a method in which a round bar stock is cut; an onion is formed by cold forging; and then a valve head is formed by cold upsetting the onion.

(4) Cold and hot forging method: a method in which a round bar or coil stock is cut; an onion is formed by cold forging; and then the onion is heated by induction heating and a valve head is formed by hot upsetting the onion. Such cold and hot forging methods are disclosed, for example, in Japanese Laid-Open Publication No.10-323735.

[0004] By the aforementioned methods for making an engine valve, it is difficult to make an elongated product having a greater ratio of its outer diameter of the mushroom-shaped portion or its valve head diameter, to its valve stem diameter ("valve head diameter/valve stem diameter," or "valve head to valve stem ratio"), because of some limitations in which it is necessary to prevent frictional resistance between the punch and the elongated blank (also referred to also as the "stock") or a buckling of the blank, when the outer diameter of an enlarged head portion of the elongated blank to be formed becomes enlarged by upsetting.

[0005] It is to be noted that there exists a need for an automotive engine valve, which is made as an elongated product having an enlarged head portion, to have a larger valve head diameter for the purpose of improving the intake/exhaust efficiency of the engine, while at the same time having a smaller valve stem diameter for the purpose of reducing weight. Thus, in order to improve the intake/exhaust efficiency, it is necessary to enlarge the intake/exhaust port areas so that the engine valve head diameters also tend to be enlarged. On the other hand, in order to improve the maximum rpm of the engine, it is necessary to improve the rapid responsiveness of the engine by reducing the engine valve weight so that the engine valve stems tend to be thin.

[0006] It is accordingly an object of the present invention to teach a method for making an elongated product having an enlarged head portion that allows for a greater ratio of the enlarged head portion outer diameter to the stem portion diameter, an elongated product made by such a method, a method for making an engine valve, an engine valve made by such a method, and forging machines used for making an elongated product having an enlarged head portion.

[0007] The aforementioned object is achieved by a method for making an elongated product having an enlarged head portion, an elongated product made by the method, a method for making an engine valve, an engine valve made by the method, and forging machines used for making an elongated product having an enlarged head portion, which are the teachings of the present invention as defined by the appended claims.

[0008] According to one embodiment of the present invention, a method for making an elongated product having an enlarged head portion is taught that may include first and second cold forging steps so as to stepwise form a smaller-diameter stem portion on one end of an elongated blank, while also including third and fourth cold forging steps so as to stepwise form an enlarged head portion on the other end of the blank.

[0009] The forging machine used in the third cold forging step has a slide punch mechanism including a punch pin that can press the other end face of the blank, a slide punch into which the punch pin and the other end of the blank are inserted, and a spring member biasing the slide punch in the pressing direction. The slide punch has a die hole into which the punch pin is inserted. The die hole includes a straight hole portion into which the punch pin is inserted with a predetermined clearance, and a tapered hole portion, which is continued from the straight hole portion, has an entrance for the blank and increases in clearance toward the entrance. The forging machine is constructed so as to form the enlarged head portion by the pressing force of the punch pin in such condition that the slide punch is engaged with the other end of the blank, and is also constructed so that the slide punch moves backward against the biasing force of the spring member by the pressure applied to the slide punch when the enlarged head portion is being enlarged.

[0010] By using such a forging machine in the third cold forging step, even if the ratio (L/D) of the length (L) to the diameter (D) of the enlarged head portion of the blank that is subsequently to be forged and formed is greater, the backward movement of the slide punch is not blocked by the frictional resistance generated between the slide punch and the blank while the portion is being upset. Also, it is possible to reduce or avoid the buckling of the blank. Accordingly,

it is possible to make an elongated product that has a greater ratio of the outer diameter of the enlarged head portion to the stem diameter of the stem portion (referred to as the head diameter to the stem diameter).

[0011] According to another embodiment of the present invention, a method for making an elongated product having an enlarged head portion is taught that may include a third cold forging step by which a projected stem portion, which is projected from the enlarged head portion and engaged into a straight hole portion of the slide punch, is formed at the other end of the blank. A forging machine used in a fourth cold forging step has a punch pin that can press the other end face of the blank, and a fixed punch into which the punch pin and the projected stem portion are inserted. The die hole of the fixed punch, into which the punch pin is inserted, has a straight hole portion into which the punch pin is inserted with a predetermined clearance, and a tapered hole portion, which is continued from the straight hole portion, has an entrance for the blank and increases in the clearance toward the entrance. The forging machine is constructed so as to form the enlarged head portion into a predetermined shape by the pressing force of the punch pin in such condition that the fixed punch is engaged with the other end of the blank.

[0012] By using such a forging machine in a fourth cold forging step, since the projected stem portion of the blank formed in the third cold forging step is inserted into the straight hole portion of the fixed punch, it is possible to form or upset the enlarged head portion into a predetermined shape with a buckling of the blank being reduced or avoided.

[0013] According to another embodiment of the present invention, a method for making an elongated product having an enlarged head portion is taught that may include a step by which the elongated product having an enlarged head portion is heated by a heating means so that in a subsequent hot forging process the enlarged head portion is more enlarged in the outer diameter and formed into a predetermined-shaped valve head portion. Accordingly, it is possible to make an engine valve having a greater ratio of the valve head to the valve stem, or an engine valve having a larger-diameter valve head portion and a smaller-diameter valve stem portion. Therefore, it is possible to improve the intake/exhaust efficiency of the engine by increasing the valve head diameter, and to provide an engine valve that allows for improving the rapid responsiveness of the engine by reducing the weight or the diameter of the valve stem portion. In addition, the combination of the cold forging step and the hot forging step for making the engine valve reduces the cost for making an engine valve having a greater ratio of the diameter of the valve head portion to the diameter of the valve stem portion.

[0014] According to another embodiment of the present invention, a forging machine used for making an elongated product having an enlarged head portion is taught that may allow for the same benefits as with the forging machine used in the third cold forging step described above.

[0015] According to another embodiment of the present invention, a forging machine used for making an elongated product having an enlarged head portion is taught that may include a die hole of a slide punch, which has a taper angle that is set in the range of 6 to 20 degrees. Accordingly, it is possible to reduce or avoid a backward-movement failure of the slide punch as well as a buckling of the blank during the upsetting and forming of the enlarged head portion of the third blank.

[0016] In other words, if the taper angle is less than 6 degrees, when the enlarged head portion of the third blank is being upset and formed the frictional resistance against the inner punch caused by the outer diameter enlargement of the third blank becomes greater than the backward-movement force, or so-called push-up force of the slide punch. Accordingly, there occurs a backward-movement failure of the inner punch or the slide punch. On the other hand, if the taper angle of the tapered hole portion is larger than 20 degrees, when the enlarged head portion 4c of the third blank is being upset and formed the backward movement of the slide punch is given at too early of a timing. Accordingly, there may occur a buckling in the blank. Therefore, by setting the taper angle of the tapered hole portion in the range of 6 to 20 degrees, it is possible to reduce or avoid a backward-movement failure of the slide punch as well as a buckling of the blank during the upsetting and forming of the enlarged head portion of the blank.

[0017] According to another embodiment of the present invention, a forging machine used for making an elongated product having an enlarged head portion is taught that may include a clearance between the straight hole portion of the die hole of the slide punch and the punch pin, which is set in the range of 2 to 5% with respect to the stem diameter of the punch pin. Accordingly, it is possible to reduce or avoid a backward-movement failure of the slide punch as well as a plastic deformation of the punch pin during the upsetting and forming of the enlarged head portion of the blank.

[0018] In other words, if the clearance between the slide punch and the punch pin is less than 2% the diameter of the punch pin is enlarged during the upsetting and forming of the enlarged head portion of the blank due to the elastic deformation of the punch pin. Then, since the clearance between the slide punch and the punch pin becomes smaller, a frictional resistance is generated blocking the backward movement (push-up movement) of the slide punch. Finally, there may occur a backward-movement failure of the slide punch. On the other hand, if the clearance between the straight hole portion and the punch pin is more than 5% there may occur a plastic deformation of the punch pin since the cross-sectional area of the punch pin becomes smaller so that an over-stress condition is generated by the load applied during the forming process. Therefore, by forming a clearance between the slide punch (or more specifically the straight hole portion of the die hole) and the punch pin so as to be 2 to 5% with respect to the diameter of the punch pin, it is possible to reduce or avoid a backward-movement failure of the slide punch as well as a plastic deformation of the

punch pin during the upsetting and forming of the enlarged head portion of the blank.

[0019] According to another embodiment of the present invention, a forging machine used for making an elongated product having an enlarged head portion is taught that may include a die hole of a slide punch with an ejection slope on the inner surface of the straight hole portion thereof, which is set in the range of 0.03 to 0.10 degrees. Accordingly, it is possible to reduce or avoid a backward-movement failure of the slide punch, as well as a buckling of the blank, during the upsetting and forming of the enlarged head portion of the blank.

[0020] In other words, if an ejection slope of less than 0.03 degrees is provided on the tapered hole portion side inner surface of the straight hole portion the outer diameter of the enlarged portion of the blank becomes so large due to the elastic deformation of the slide punch that a frictional resistance blocking the backward movement of the slide punch is generated during the upsetting and forming of the enlarged head portion of the blank. Finally, there may occur a backward-movement failure of the slide punch. On the other hand, if an ejection slope of more than 0.10 degrees is provided on the tapered hole portion side inner surface of the straight hole portion the slide punch cannot be served as stopper to prevent a buckling of the blank since too much clearance is formed between the slide punch (or more specifically the straight hole portion of the die hole) and the blank. Finally, there may occur a buckling in the blank. Therefore, by setting the ejection slope in the range of 0.03 to 0.10 degrees, it is possible to reduce or avoid a backward-movement failure of the slide punch, as well as a buckling of the blank during the upsetting and forming of the enlarged head portion of the blank.

[0021] According to another embodiment of the present invention, a forging machine used for making an elongated product having an enlarged head portion is taught that may include a punch pin with a diametral relief in the range of 0.1 to 0.5 mm on the outer surface of the pin body, or a portion other than the distal end portion of the punch pin. Accordingly, it is possible to reduce or avoid a backward-movement failure of the slide punch as well as a plastic deformation of the punch pin during the upsetting and forming of the enlarged head portion of the blank.

[0022] In other words, if a diametral relief of less than 0.1 mm is provided on the outer surface of the pin body of the punch pin the diameter of the punch pin is enlarged during the upsetting and forming of the enlarged head portion of the blank due to the elastic deformation of the punch pin. Then, since the clearance between the punch pin and the slide punch becomes smaller, a frictional resistance is generated blocking the backward movement (push-up movement) of the slide punch. Finally, there may occur a backward-movement failure of the slide punch. On the other hand, if a diametral relief of more than 0.5 mm is provided, there may occur a plastic deformation of the punch pin since the cross-sectional area of the pin body of the punch pin becomes smaller so that a over-stress condition is generated by the load applied during the forming process. Accordingly, by forming the pin body of the punch pin so that the outer surface of the main portion has a diametral relief in the range of 0.1 to 0.5 mm, it is possible to reduce or avoid a backward-movement failure of the slide punch as well as a plastic deformation of the pin body of the punch pin during the upsetting and forming of the enlarged head portion of the third blank.

[0023] Thus, according to the present invention, it is possible to teach a method for making an elongated product having an enlarged head portion that allows for a greater ratio of the enlarged head portion outer diameter to the stem portion diameter, an elongated product made by such a method, a method for making an engine valve, an engine valve made by such a method, and forging machines used for making an elongated product having an enlarged head portion.

[0024] Additional objects, features and advantages of the present invention will be readily understood after reading the following detailed description together with the claims and the accompanying drawings, in which:

FIGS. 1(a) to 1(f) illustrate forging steps of an engine valve: FIG. 1(a) is a side view showing an elongated blank; FIG. 1(b) is a side view showing the blank finished through a first cold forging step; FIG. 1(c) is a side view showing the blank finished through a second cold forging step; FIG. 1(d) is a side view showing the blank finished through a third cold forging step; FIG. 1(e) is a side view showing the blank finished through a fourth cold forging step; and FIG. 1(f) is a side view showing an engine valve finished through a fifth hot forging step;

FIG. 2(a) to 2(e) illustrate forging apparatus used in the cold forging steps: FIG. 2(a) is a cross-sectional view showing a cutting station; FIG. 2(b) is a cross-sectional view showing a first cold forging station; FIG. 2(c) is a cross-sectional view showing a second cold forging station; FIG. 2(d) is a cross-sectional view showing a third cold forging station; and FIG. 2(e) is a cross-sectional view showing a fourth cold forging station;

FIG. 3 is a cross-sectional view showing a forging machine according to the third cold forging step;

FIGS. 4(a) to 4(c) illustrate an upsetting process by a slide punch mechanism: FIG. 4(a) is a cross-sectional view showing a upsetting starting state; FIG. 4(b) is a cross-sectional view showing a mid-upsetting state; and FIG. 4(c) is a cross-sectional view showing an upsetting completion state;

FIG. 5 is a cross-sectional view showing a punch pin;

FIG. 6 is a cross-sectional view showing an inner punch;

FIG. 7 illustrates a die hole of the inner punch;

FIG. 8 illustrates a taper angle of a tapered hole portion of the inner punch;

FIG. 9 is a characteristic curve diagram showing relationships between a taper angle of the tapered hole of the inner

punch and a push-up force by a slide punch;

FIG. 10 is a characteristic curve diagram showing relationships between a ratio of a clearance between the slide punch and the punch pin to a stem diameter of the punch pin, and an eccentric load applied to the punch pin; and FIG. 11 illustrates a relationship of a valve head to valve stem ratio of an engine valve.

[0025] Each of the additional features and teachings disclosed above and below may be utilized separately or in conjunction with other features and teachings to provide an improved method for making an elongated product having an enlarged head portion, an improved method for making an engine valve, and improved forging machines used for making an elongated product having an enlarged head portion. Representative examples of the present invention, which examples utilize many of these additional features and teachings both separately and in conjunction with each other, will now be described in detail with reference to the attached drawings. This detailed description is merely intended to teach a person of skill in the art further details for practicing preferred aspects of the present teachings and is not intended to limit the scope of the invention. Only the claims define the scope of the claimed invention. Therefore, combinations of features and steps disclosed in the following detailed description may not be necessary to practice the invention in the broadest sense, and are instead taught merely to particularly describe representative examples of the invention. Moreover, various features of the representative examples and the dependent claims may be combined in ways that are not specifically enumerated in order to provide additional useful embodiments of the present teachings.

[0026] Representative embodiments of the present invention will be described below by way of examples.

[0027] Referring now to the drawings, one embodiment will be described. This embodiment exemplifies a method for making an automobile engine valve, and forging apparatus used therein.

[0028] An engine valve 6 or the product showed in FIG. 1(f) is made from an elongated blank 1 as a stock (see FIG. 1(a)) through five forging steps from (b) to (f). The elongated blank 1 shown in FIG. 1(a) is a round-rod shaped steel, for example, having a Vickers hardness number (Hv) in the range of 180 to 300, made, for example, of a heat resisting steel SUH11 cold forging coil stock. This blank, for example, has a stem length (total length) 1L of 88.3 mm, and a stem diameter 1D of approximately 10.3 mm.

[0029] As shown in FIG. 1(b), the blank 2 (referred to as the "first blank"), finished through the first cold forging step, has a main stem portion 2a and a projected stem portion 2c that is continued from one end (a lower end in FIG. 1) of the main stem portion 2a via a diameter-reducing stem portion 2b that is generally tapered. The outer surface of the diameter-reducing stem portion 2b is provided at the proximal end of the projected stem portion 2c with a rounded area 2d having a convex arc shape in an axial cross-section. This rounded area 2d is made for the purpose of softening an abutment impact of the diameter-reducing stem portion 2b when the first blank 2 is inserted into the upper opening portion of a die hole 22a in a die 22 of a forging machine 20 (see FIG. 2(c)) in the next step (a third cold forging step) as described below. For example, dimensions of this first blank 2 are as follows: the projected stem portion 2c has a stem length 2cL of approximately 6 mm; the remaining portion other than the projected stem portion 2c has a stem length 2nL of 82.6 mm; and the main stem portion 2a has a stem diameter 2aD of approximately 10.55 mm.

[0030] As shown in FIG. 1(c), the blank 3 (referred to as the "second blank"), finished through the second cold forging step, has a main stem portion 3a and a smaller-diameter stem portion 3c that is continued from one end (a lower end) of the main stem portion 3a via a diameter-reducing stem portion 3b that is generally tapered. The outer surface of the diameter-reducing stem portion 3b is provided at the proximal end of the smaller-diameter stem portion 3c with a rounded area 3d having a convex arc shape in an axial cross-section. This rounded area 3d is made for the purpose of softening an abutment impact of the diameter-reducing stem portion 3b when the second blank 3 is inserted into the upper opening portion of a die hole 32a in a die 32 of a forging machine 30 in the next step (a fourth cold forging step) as described below. For example, dimensions of this second blank 3 are as follows: the smaller-diameter stem portion 3c has a stem length 3cL of 70.7 mm; the remaining portion other than the smaller-diameter stem portion 3c has a stem length 3nL of approximately 55.2 mm; the diameter-reducing stem portion 3b has a stem length 3bL of 12 mm; the main stem portion 3a has a stem diameter 3aD of approximately 10.65 mm; and the smaller-diameter stem 3c has a stem diameter 3cD of 6.75 mm.

[0031] As shown in FIG. 1(d), the blank 4 (referred to as the "third blank"), finished through the third cold forging step, in order from its upper end to its lower end in FIG. 1(d) has a projected stem portion 4a, an enlarged head portion 4c that is continued from the projected stem portion 4a via a tapered portion 4b, a smaller-diameter stem portion 4e that is continued from the enlarged head portion 4c via a diameter-reducing stem portion 4d that is generally tapered, and a stem end portion 4f that is continued from the smaller-diameter stem portion 4e. For example, dimensions of this third blank 4 are as follows: the smaller-diameter stem portion 4e has a stem length 4eL of 63 mm; the stem end 4f has a stem length 4fL of 11 mm; the remaining portion other than the smaller-diameter stem portion 4e and the stem end 4f has a stem length 4nL of 40.8 mm; the projected stem portion 4a has a stem length 4aL of 18 mm; and the enlarged head portion 4c has a stem length 4cL of 5 mm. Moreover, the projected stem portion 4a has a stem diameter 4aD of 10.7 mm; the enlarged head portion 4c has an outer diameter (stem diameter) 4cD of 16.0 mm; the smaller-diameter stem portion 4e has a stem diameter 4eD of approximately 6.75 mm; and the stem end portion 4f has a stem diameter

4fD of 5.77 mm. It is to be noted that an outer surface at the connecting portion between the projected stem portion 4a and the tapered portion 4b is concavely curved, for example, with a curvature radius 4hR of 20 mm.

[0032] With respect to the third cold forging step, the second blank 3 (see FIG. 1(c)), before the upsetting of the third cold forging step, has a stem length 3nL of approximately 55.2 mm and the stem diameter 3aD of approximately 10.65 mm, as described above. Thus, a ratio (L/D) of the length (L) to the diameter (D) of the stock that is subject to the third cold forging step is estimated as follows:

$$L/D = 55.2/10.65 = 5.18$$

$$L/D > 4.0$$

where 4.0 means the formability limit ratio of the formable length to the diameter of the stock processed by the conventional art. Consequently, the ratio (L/D) of the formable length (L) to the diameter (D) is found to be larger than the conventional maximum value or 4.0.

[0033] As shown in FIG. 1(e), the blank 5 (referred to as the "fourth blank"), finished through the third cold forging step, in order from its upper end to its lower end in FIG. 1 has a projected stem portion 5a, an enlarged head portion 5c that is continued from the projected stem portion 5a via a tapered portion 5b, a smaller-diameter stem portion 5e that is continued from the enlarged head portion 5c via a diameter-reducing stem portion 5d that is generally tapered, and a stem end portion 5f that is continued from the smaller-diameter stem portion 5e. For example, the dimensions of this fourth blank 5 are as follows: the total length 5L is approximately 126.7 mm; the stem end 5f has a stem length 5fL of approximately 29.2 mm; the smaller-diameter stem portion 5e including the stem end portion 5f has a stem length 5eL of approximately 92.2 mm; the remaining portion other than the smaller-diameter stem portion 5e has a stem length 5nL of 34.5 mm; the projected stem portion 5a has a stem length 5aL of 10 mm; and the enlarged head portion 5c has a stem length 5cL of 6.45 mm. Moreover, the projected stem portion 5a has a stem diameter 5aD of approximately 10.8 mm; the enlarged head portion 5c has an outer diameter 5cD of approximately 18.3 mm; the smaller-diameter stem portion 5e has a stem diameter 5eD of approximately 5.8 mm; the stem end portion 5f has a stem diameter 5fD of approximately 5.77 mm. It is to be noted that the tapered portion 5b has a taper angle 5b θ of 20 degrees. Also, an outer surface at the connecting portion between the projected stem portion 5a and the tapered portion 5b is concavely curved, for example, with a curvature radius 5hR of 20 mm. Furthermore, an outer surface of the diameter-reducing stem portion 5d is concavely curved, for example, with a curvature radius 5iR of 8 mm.

[0034] With respect to the fourth cold forging step, the third blank 4 (see FIG. 1(d)), before the upsetting in the fourth cold forging step, has a portion to be upset, which includes the stem length 4nL of approximately 40.8 mm and the outer diameter (stem diameter) 4aD of approximately 10.7 mm, as described above. Thus, a ratio (L/D) of the length (L) to the diameter (D) of the stock that is subject to the fourth cold forging step is estimated as follows:

$$L/D = 40.8/10.7 = 3.81$$

$$L/D > 2.5$$

where 2.5 means the formability limit ratio of the formable length to the diameter of the stock processed by the conventional art. Consequently, the ratio (L/D) of the formable length (L) to the diameter (D) is found to be greater than the conventional maximum value, 2.5. It is to be noted that the blank 5 (see FIG. 1(e)), finished through the fourth cold forging step, is equivalent to the "elongated product" used herein.

[0035] Then, as shown in FIG. 1(f), an engine valve 6, or a product having a disk-shaped valve head 6a at the tip portion (the upper portion in FIG. 1(f)) of a stem portion is formed after finishing with the fifth hot forging step. Dimensions of this product 6 are as follows: the total length (stem length) 6L is approximately 110 mm; the stem portion 6b has a stem length of approximately 95 mm; the valve head 6a has an outer diameter (a valve head diameter) 6aD of 38 mm; the stem portion 6b has a stem diameter 6bD of approximately 5.5 mm; the valve head/valve stem ratio is 6.9.

[0036] The forging apparatus used in the first to fourth cold forging steps will now be described with reference to FIGS. 2(a) to 2(e). A multi-stage transfer press system (not shown), which is referred to as a bolt former or a nut former, is used as this forging apparatus. As shown in FIGS. 2(a) to 2(e), this transfer press system is constructed and arranged so that the cutting station SC, the first cold forging station S1, the second cold forging station S2, the third cold forging

station S3, and the fourth cold forging station S4, are equally spaced from FIG. 2(a) to FIG. 2(e).

[0037] As shown in FIG. 2(a), the cutting station SC has a die block 7 that is provided with a shearing die 8 having a die hole 8a. A cold forging coil stock C is inserted from below the die block 7 into the die hole 8a of the shearing die 8, and, as shown as a dash-double-dot line C in FIG. 2(a), is projected above the shearing die 8 by the length corresponding to the stem length 1L of the blank 1 (see FIG. 1(a)). Then, in this condition, a cutter 9 that is in a waiting position (see a dash-double-dot line 9 in FIG. 2(a)) travels toward the first cold forging station S 1 (to the right in FIG. 2(a)). A blank 1 is sheared or cut by the cutter 9 from the cold forging coil stock C. Then, the blank 1 is transferred to the first cold forging station S1.

[0038] The first to fourth forging stations are respectively provided with forging machines 10, 20, 30, and 40. Each forging machine 10, 20, 30, or 40 respectively includes a die 12, 22, 32, or 42 provided in a die block 7 of the transfer press system, and a punch 15, 25, 35, or 45 provided respectively in a ram 50 that reciprocates with respect to the die block 7. A projecting pin 13, 23, 33, or 43 is respectively inserted into each die 12, 22, 32, or 42 from therebelow, and is slidable in an axial direction (up or down direction) therewithin. Also, each die 12, 22, 32, or 42 is respectively supported by a die holder 11, 21, 31, or 41.

[0039] The forging machine 10 of the first cold forging station S1, the forging machine 20 of the second cold forging station S2, the forging machine 40 of the fourth cold forging station S4, and the forging machine 30 of the third cold forging station S3 will be described below in this order.

[0040] Firstly, the forging machine 10 of the first cold forging station S 1 will be described. As shown in FIG. 2(b), a die hole 12a in the die 12 of the forging machine 10 is formed in a shape corresponding to the first blank 2 (FIG. 1(b)). With respect to a punch 15 of the forging machine 10, a tip portion or a lower end portion of a punch pin 16 is inserted into the die hole 12a of the die 12 by a predetermined length, by means of the advancing end or the lowering end of the ram 50.

[0041] Secondly, the forging machine 20 of the second cold forging station S2 will be described. As shown in FIG. 2(c), a die hole 22a in the die 22 of the forging machine 20 is formed in a shape corresponding to the second blank 3 (FIG. 1(c)). With respect to a punch 25 of the forging machine 20, a tip portion or a lower end portion of a punch pin 26 is inserted into the die hole 22a of the die 22 by a predetermined length, by means of the advancing end or the lowering end of the ram 50.

[0042] Thirdly, the forging machine 40 of the fourth cold forging station S4 will be described. As shown in FIG. 2(e), a die hole 42a in the die 42 of the forging machine 40 is formed in a shape corresponding to the diameter-reducing stem portion 5d, the smaller-diameter stem portion 5e, and the stem end portion 5f of the fourth blank 5 (FIG. 1(e)).

[0043] On the other hand, the punch 45 of the forging machine 40 has a die hole 45a corresponding to the projected stem portion 5a and the tapered portion 5b of the fourth blank 5 (see FIG. 1(e)). A punch pin 46 is inserted into the die hole 45a provided around the central axis of the punch 45, slidably in an axial direction (up or down direction) within the die hole 45a. When the advancing end or the lowering end of the ram 50 approaches near the top surface of the die 42, the die hole 45a cooperates with the die hole 42a of the die 42 and forms a die cavity generally corresponding to the fourth blank 5. It is to be noted that the punch 45 is equivalent to the "fixed punch" used herein.

[0044] Also, the die hole 45a of the fixed punch 45, into which the punch pin 46 is inserted, has a straight hole portion 45b and a tapered hole portion 45c. On one hand, the punch pin 46 as well as the projected stem portion 4a of the third blank 4 (see FIG. 1(d)) is inserted into the straight hole portion 45b with a predetermined clearance. The tapered hole portion 45c, on the other hand, is continued from the straight hole portion 45b and gradually increases in the clearance toward the entrance for the blank 4, forming the tapered portion 5b of the fourth blank 5 (see FIG. 1(e)). In addition, the forging machine 40 is constructed so as to upset or form the enlarged head portion 4c (5c) into a predetermined shape by the pressing force of the punch pin 46 in such condition that the fixed punch 45 is engaged with the other end of the blank or the upper end portion of the third blank 4 (see FIG. 1(d)).

[0045] Fourthly, the forging machine 30 of the third cold forging station S3 will be described referring to FIG. 3.

[0046] A die hole 32a in the die 32 of the forging machine 30 is formed in a shape corresponding to the diameter-reducing stem portion 4d, the smaller-diameter stem portion 4e, and the stem end portion 4f of the third blank 4 (FIG. 1(d)). On the other hand, a punch 35 of the forging machine 30 has a slide punch mechanism SP. The slide punch mechanism SP has a punch pin 36, as well as a slide punch 37, a spring member 38, and an engagement tube 39.

[0047] The punch pin 36 is constructed so as to be able to slide in an axial direction (up or down direction) along with the central axis of the punch 35 and to press the top surface of the second blank 3 (the third blank 4). On the other hand, the slide punch 37 integrally has an inner punch 70 and an outer punch 75. The inner punch 70 has a die hole 71, into which the punch pin 36 is inserted slidably in an axial direction (up or down direction). The die hole 71 corresponds to the projected stem portion 4a and the tapered portion 4b of the third blank 4. When the advancing end or the lowering end of the ram 50 approaches near the top surface of the die 32, the inner punch 70 cooperates with the die hole 32a of the die 32 and forms a die hole generally corresponding to the third blank 4.

[0048] In addition, the outer punch 75 is slidably provided in an axial direction (up or down direction) within a holder tube 52 that is fixed in the ram 50. The inner punch 70 is secured within the lower portion of the outer punch 75.

[0049] The engagement tube 39 is slidably provided in an axial direction (up or down direction) within the upper portion of the outer punch 75. The engagement tube 39 is constructed so as to be able to push and move the slide punch 37 (the inner punch 70 and the outer punch 75) downward. Also, a pressing pin 53 that presses the punch pin 36 is provided with a guide 54 that is slidably fitted in an axial direction (up or down direction) within the engagement tube 39.

[0050] A spring member 38 is held between a spring seat 51 on the ram 50 and a flange portion 39a of the engagement tube 39. The spring member 38 constantly biases the engagement tube 39 downward with a predetermined biasing force. As described above, the slide punch mechanism SP is constructed so as to form the enlarged head portion 4c by the pressing force of the punch pin 36 in such condition that the slide punch 37 is engaged with the upper portion of the second blank 3 that is inserted into the die hole 32a of the die 32. The slide punch mechanism SP is also constructed so that the slide punch 37 moves backward against the biasing force of the spring member 38 by the pressure applied to the slide punch 37 when the enlarged head portion 4c is being enlarged.

[0051] As shown in FIG. 5, the punch pin 36 has a pin body 60 of a predetermined stem length and a pin guide 65 that is fastened to the proximal end (the upper end) portion of the pin body 60. For example, the distal end portion 62 of the pin body 60 has a stem length 62L of 5 mm and a stem diameter 62D of approximately 10.65 mm. The outer surface of the main portion 61 or the portion other than the distal end portion 62 of the pin body 60 is shaped so that a stem diameter 61D is, for example, approximately 10.45 mm. Thus, the outer surface of the main portion 61 of the pin body 60 has a diametral relief 63 with respect to the outer surface of the distal end portion 62. The diametral relief 63 is estimated as follows: $62D - 61D = 10.65 \text{ mm} - 10.45 \text{ mm} = 0.2 \text{ mm}$.

[0052] If the diametral relief 63 of the pin body 60 of the punch pin 36 has the range of 0.1 to 0.5 mm, it is possible to reduce or avoid a backward-movement failure of the slide punch 37, as well as a plastic deformation of the pin body 60 of the punch pin 36, during the upsetting and forming of the enlarged head portion 4c of the third blank 4 (see FIG. 1(d)).

[0053] For example, if the diametral relief 63 is less than 0.1 mm, there may occur a backward-movement failure of the slide punch 37. This is because: the pin body 60 of the punch pin 36 is elastically deformed during the upsetting and forming of the enlarged head portion 4c of the third blank 4; the stem diameter of the pin body 60 becomes enlarged; the clearance between the pin body 60 of the punch pin 36 and the slide punch 37 becomes smaller; and finally a frictional resistance is generated blocking the backward movement (push-up movement) of the slide punch 37.

[0054] On the other hand, if the diametral relief 63 of the pin body 60 is more than 0.5 mm, there may occur a plastic deformation of the pin body 60 of the punch pin 36. This is because such relief results in a smaller cross-section of the pin body 60 of the punch pin 36 so that an over-stress condition is generated by the load applied during the forming process.

[0055] Accordingly, by forming the pin body 60 of the punch pin 36 so that the outer surface of the main portion 61 has a diametral relief 63 in the range of 0.1 to 0.5 mm, it is possible to reduce or avoid a backward-movement failure of the slide punch 37, as well as a plastic deformation of the pin body 60 of the punch pin 36, during the upsetting and forming of the enlarged head portion 4c of the third blank 4.

[0056] As shown in FIG. 6, the die hole 71 of the inner punch 70 has a straight hole portion 72, an entrance 73 for the blank 4, and a tapered hole portion 76. On one hand, the pin body 60 of the punch pin 36 (see FIG. 5) is inserted into the straight hole portion 72 with a predetermined clearance. The tapered hole portion 76, on the other hand, is continued from the straight hole portion 72 and gradually increases in clearance downward or toward the entrance 73 for the blank 4.

[0057] As shown in FIG. 7, the tapered hole portion 76 of the die hole 71 of the inner punch 70 has a taper angle α that is set in the range of 6 to 20 degrees. This setting of α is more specifically shown in FIG. 8.

[0058] As shown in FIG. 8, an effective forming length of the straight hole portion 72 of the die hole 71 is L_1 ; an effective forming length of the tapered hole portion 76 is L_2 ; and a forming pressure applied perpendicularly to the surface of the tapered hole portion 76 is P . In this case, a pressing force (a biasing force) of the slide punch 37 as applied by the spring member 38 (see FIG. 3) is negligible.

[0059] The push-up force P_1 per unit area, which is applied in such a direction that the inner punch 70 is pushed up, is estimated by:

$$P_1 = P \sin \alpha .$$

[0060] Meanwhile, the frictional resistance P_2 against each surface of the straight hole portion 72 and the tapered hole portion 76 is estimated by:

$$P_2 = \mu \cdot P,$$

where μ is a friction coefficient.

[0061] Then, the resistance force P_3 per unit area in opposition to the push-up force P_1 , is estimated by:

$$P_3 = \mu \cdot P \cos \alpha .$$

[0062] Accordingly, the push-up force F_A , which is required for the inner punch 70 to be raised, is estimated by:

$$F_A = P L_2 \cdot \sin \alpha .$$

[0063] Also, the frictional resistance F_S in opposition to the push-up force P_1 per unit area, is estimated by:

$$F_S = \mu \cdot P L_1 + \mu \cdot P L_2 \cdot \cos \alpha = \mu \cdot P (L_1 + L_2 \cdot \cos \alpha) .$$

Therefore, if the condition, $P L_2 \cdot \sin \alpha > \mu \cdot P (L_1 + L_2 \cdot \cos \alpha)$, is satisfied, the inner punch 70 can be raised in opposition to the frictional resistance F_S .

[0064] If L_1 is negligible, the inequality is then:

$$\sin \alpha > \mu \cdot \cos \alpha .$$

So:

$$\tan \alpha > \mu .$$

If the friction coefficient is given as $\mu = 0.1$, then:

$$\alpha > 5.71 \text{ degrees} .$$

[0065] Consequently, the taper angle α should be set at more than 6 degrees. In other words, if the taper angle α is less than 6 degrees, while the enlarged head portion 4c of the third blank 4 (see FIG. 1(d)) is being upset and formed, the frictional resistance F_S against the inner punch 70 caused by the outer diameter enlargement of the third blank 4 becomes greater than the push-up force F_A of the inner punch 70. Accordingly, there may occur a backward-movement failure of the inner punch 70 or the slide punch 37.

[0066] On the other hand, if the taper angle α of the tapered hole portion 76 is greater than 20 degrees, while the enlarged head portion 4c of the third blank 4 (see FIG. 1(d)) is being upset and formed, the backward movement of the inner punch 70 or the slide punch 37 is given at too early of a timing. Accordingly, there may occur a buckling in the blank 4.

[0067] Therefore, by setting the taper angle α of the tapered hole portion 76 in the range of 6 to 20 degrees, it is possible to reduce or avoid a backward-movement failure of the slide punch 37 as well as a buckling of the blank during the upsetting and forming of the enlarged head portion 4c of the third blank 4.

[0068] FIG. 9 is a characteristic curve diagram showing relationships between the taper angle α and the push-up force P_1 . In FIG. 9, the horizontal axis is the taper angle α (see FIG. 8) of the tapered hole portion 76 of the inner punch 70, while the vertical axis is the push-up force P_1 (see FIG. 8) of the inner punch 70 or the slide punch 37. In the diagram, a characteristic curve M_1 shows the frictional resistance with respect to the slide punch 37 at an earlier stage, while a characteristic curve M_2 shows the frictional resistance with respect to the slide punch 37 at a later stage. A characteristic curve N_1 shows a push-up force with respect to the slide punch 37 at an earlier stage, while a characteristic curve N_2 shows a push-up force with respect to the slide punch 37 at a later stage.

[0069] As shown in FIG. 9, the characteristic curve M_1 and the characteristic curve N_1 intersect near the taper angle α of 20 degrees, while the characteristic curve M_2 and the characteristic curve N_2 intersect near the taper angle α of 6

degrees. Therefore, as apparent from FIG. 9, if the taper angle α is in the range of 6 to 20 degrees, it is possible to reduce or avoid a backward-movement failure of the slide punch 37.

[0070] Referring again to FIG. 6 showing the die hole 71 of the inner punch 70 and FIG. 5 showing the pin body 60 of the punch pin 36, the clearance between the surface of the straight hole portion 72 (see FIG. 6) and the outer surface of the main portion 61 (see FIG. 5) is set in the range of 2 to 5% with respect to the stem diameter 61D of the main portion 61 of the pin body 60. Accordingly, it is possible to reduce or avoid a backward-movement failure of the slide punch 37 as well as a plastic deformation of the pin body 60 of the punch pin 36 during the upsetting and forming of the enlarged head portion 4c of the third blank 4 (see FIG. 1(d)).

[0071] It is to be noted that in the case of an engine valve material such as a heat resisting steel of SUH3, the forming pressure σ of the upsetting process is approximately 2,000 MPa. In this condition, the deformation ε in an axial direction of the punch pin 61 is estimated by:

$$\varepsilon = \sigma / E = 2000 / (211.4 \times 10^3) = 0.00946,$$

where E denotes the elastic coefficient.

[0072] If the Poisson's ratio ν is equal to 0.3, then the radial enlargement amount W is estimated by:

$$W = \varepsilon \nu = 0.00946 \times 0.3 = 0.28 (\%).$$

[0073] Therefore, if the clearance between the surface of the straight hole portion 72 and the outer surface of the main portion 61 of the pin body 60 is less than 2%, there may occur a backward-movement failure of the inner punch 70 of the slide punch 37. This is because: the main portion 61 of the pin body 60 is elastically deformed during the upsetting and forming of the enlarged head portion 4c of the third blank 4; the stem diameter of the pin body 60 becomes enlarged; the clearance becomes much smaller, e.g. less than 1.62%; and finally a frictional resistance blocking the backward movement (push-up movement) of the slide punch 37 is triggered, for example, by solid materials mixed in the lubrication oil.

[0074] On the other hand, if the clearance is more than 5%, there may occur a plastic deformation of the main portion 61 of the pin body 60. This is because the cross-sectional area of the main portion 61 of the pin body 60 becomes smaller so that a over-stress condition is generated by the load applied during the forming process.

[0075] It is to be noted that if the clearance is 5%, then the diameter of the punch pin 36 is 0.95 times as large as the inner diameter of the straight hole portion 72 of the inner punch 70. In this condition, the area that receives the pressure during upsetting is estimated at 0.952, which is nearly equal to 0.9. This means that the pressure receiving area is reduced by approximately 10%. Consequently, there may exist a case where the compression stress of the punch pin 36 exceeds the withstand pressure of the die material, because the compression stress of the punch pin 36 is 1 / 0.9 times greater.

[0076] Therefore, by forming the clearance so as to be 2 to 5% of the stem diameter 61 D of the main portion 61 of the pin body 60, it is possible to reduce or avoid a backward-movement failure of the slide punch 37 as well as a plastic deformation of the pin body 60 of the punch pin 36 during the upsetting and forming of the enlarged head portion 4c of the third blank 4.

[0077] FIG. 10 shows a relationship between the percentage of clearance (%) and the eccentric load applied to the pin body 60 of the punch pin 36. In FIG. 10, the horizontal axis is the percentage of the clearance (%), while the vertical axis is the eccentric load.

[0078] As apparent from the characteristic curve A shown in FIG. 10, if the percentage of the clearance is set in the range of 2 to 5%, it is possible to reduce or avoid a backward-movement failure of the slide punch 37.

[0079] As already shown in FIG. 7, with respect to the inner punch 70, an ejection slope β is provided on the inner surface of the straight hole portion 76 of the die hole 71. The ejection slope β is set in the range of 0.03 to 0.10 degrees. Due to this, it is possible to reduce or avoid a backward-movement failure of the inner punch 70 of the slide punch 37 as well as the plastic deformation of the blank 4 during the upsetting and forming of the enlarged head portion 4c of the third blank 4 (see FIG. 1(d)).

[0080] For example, if the ejection slope β is less than 0.03 degrees, the ejection slope may be cancelled out as the pressure difference between the inner pressure around the distal end portion 62 of the pin body 60 and the inner pressure located 10 mm away from the punch pin 36 becomes greater than 300 MPa during the upsetting and forming of the enlarged head portion 4c of the third blank 4. If the pressure difference is greater than this, then the inner surface of the straight hole portion 76 becomes inversed tapered so that the backward movement of the inner punch 70 is blocked.

On the other hand, if the ejection slope β is more than 0.10 degrees, then the clearance is so large that the blank entrance portion 73 of the inner punch 70 cannot fasten the blank 4. Accordingly, there may occur a buckling in the blank 4.

[0081] Therefore, by setting the ejection slope β in the range of 0.03 to 0.10 degrees, it is possible to reduce or avoid a backward-movement failure of the slide punch 37 as well as a buckling of the blank during the upsetting and forming of the enlarged head portion 4c of the third blank 4.

[0082] It is to be noted that the aforementioned numerical value settings such as the diametral relief 63 of the punch pin 36 (see FIG. 5), the taper angle α and the ejection slope β of the inner punch 70 (see FIG. 7), or the clearance between the straight hole portion 72 and the pin body 60, are well suited for using as the cold forging coil stock C a steel material with a Vickers hardness of 180 to 300.

[0083] Also, the forging apparatus already shown in FIGS. 2(a) to 2(e) is constructed and arranged so that each blank 2, 3, 4, or 5 projected from each die 12, 22, 32, or 42 by each projecting pin 13, 23, 33, or 43 in every forging step are transferred to a downstream forging station by a well-known blank transferring system (not shown).

[0084] Referring again to FIGS. 2(a) to 2(e) showing the forging apparatus, steps for making a blank 1 to a fourth blank 5 will be described below.

[0085] Firstly, a blank 1 having a predetermined stem length L_1 is sheared or cut by the cutter 9 from the cold forging coil stock C. Then, the blank 1 is transferred to the first cold forging station S1.

[0086] Then, the blank 1 is forged and formed into a first blank 2 by the forging machine 10 of the first cold forging station S1. The first blank 2 is transferred to the second cold forging station S2 by the blank transferring system.

[0087] The first blank 2 is then forged and formed into a second blank 3 by the forging machine 20 of the second cold forging station S2. The second blank 3 is transferred to the second cold forging station S3 by the blank transferring system.

[0088] Then, the second blank 3 is forged and formed into a first blank 2 by the forging machine 30 of the third cold forging station S3. The third blank 4 is transferred to the fourth cold forging station S4 by the blank transferring system.

[0089] Then, the third blank 4 is forged and formed into a fourth blank 5 by the forging machine 40 of the fourth cold forging station S4.

[0090] The fourth blank 5 made as described above (see FIG. 1(e)) is further transferred to a hot forging station (not shown) by the blank transferring system. In the hot forging station, the enlarged head portion of the fourth blank 5, including the projected stem portion 5a, the tapered portion 5b, and the enlarged head portion 5c, is heated and softened by a heating means. The outer diameter 5cD (see FIG. 1(e)) is then more enlarged and formed into a valve head 6a in a predetermined shape (see FIG. 1(f)) by a forging apparatus (not shown). Finally, the product or an engine valve 6 is made. It should be noted that the forging apparatus or the heating means of the hot forging station are constructed the same as for well-known devices and will not be described herein.

[0091] Referring now to FIG. 4, an upsetting process by the slide punch mechanism SP of the forging machine 30 (see FIG. 3) of the third cold forging station S3 will be described below.

[0092] Firstly, as shown in FIG. 4(a), at the start of the upsetting, the slide punch 37 (i.e. the inner punch 70 and the outer punch 75) is lowered by the biasing force of the spring member 38. Afterward, the punch pin 36 is lowered.

[0093] Then, as shown in FIG. 4(b), in the middle of the upsetting, the slide punch 37 (i.e. the inner punch 70 and the outer punch 75) is raised by the stock upset by the punch pin 36. Accordingly, it is possible to upset and form the enlarged head portion 4c without causing buckling, while the load applied to the punch pin 36 during the forming process is at the same level as in a conventional forging machine, from the closed upsetting state (see FIG. 4(a)) to the open upsetting state (see FIG. 4(c)).

[0094] According to the method for making the blank 5 having the enlarged head portion 5c, the smaller-diameter stem portion 5e is formed at one end of the blank by the first and second cold forging steps, while the enlarged head portion 5c is formed at the other end of the blank by the third and fourth cold forging processes (see FIGS. 2(a) to 2(e)).

[0095] Moreover, the forging machine 30 (see FIG. 3), used for the third cold forging step, has a punch pin 36 that can press the other end face of the blank, a slide punch 37 into which the punch pin 36 and the other end of the blank are inserted, and a slide punch mechanism SP including a spring member 38 biasing the slide punch 37 in the pressing direction. The die hole 71 of the inner punch 70 of the slide punch 37, into which the punch pin 36 is inserted, has the straight hole portion 72 into which the pin body 60 of the punch pin 36 is inserted with a predetermined clearance, and the tapered hole portion 76 that is continued from the straight hole portion 72 and increases in clearance toward the entrance for the blank. Moreover, the forging machine 30 used for the third cold forging step is constructed so as to form the enlarged head portion 4c by the pressing force of the punch pin 36 in such condition that the slide punch 37 is engaged with the other end of the blank, and is also constructed so that the slide punch 37 moves backward against the biasing force of the spring member 38 by the pressure applied to the slide punch 37 when the enlarged head portion 4c is being enlarged.

[0096] By using such a forging machine 30 in the third cold forging step, even if the ratio (L/D) of the length (L) to the diameter (D) of the enlarged head portion 4c of the blank that is subsequently to be forged and formed is greater, the backward movement of the slide punch 37 is not blocked by the frictional resistance generated between the slide punch 37 and the blank when the portion is upset. Also, it is possible to reduce or avoid the buckling of the blank. Accordingly,

it is possible to make the blank 3 having a large ratio of the head diameter to the stem diameter (see FIG. (d)).

[0097] As shown in FIG. 3, the projected stem portion 4a, which is projected from the enlarged head portion 4c and engaged into the straight hole portion 72 of the slide punch 37, is formed at the other end of the blank in the third cold forging step. As shown in FIG. 2(e), the forging machine 40 used for the fourth cold forging step has a punch pin 46 that can press the other end face of the blank, and a fixed punch 45 into which the punch pin 46 and the projected stem portion 4a are inserted. Also, the die hole 45a of the fixed punch 45, into which the punch pin 46 is inserted, has the straight hole portion 45b into which the punch pin 46 is inserted with a predetermined clearance, and the tapered hole portion 45c that is continued from the straight hole portion 45b and increases in the clearance toward the entrance for the blank. Moreover, the forging machine 40 is constructed so as to form the enlarged head portion 4c (5c) into a predetermined shape by a pressing force of the punch pin 46 in such condition that the fixed punch 45 is engaged with the other end of the blank.

[0098] By using such forging machine 40 in the fourth cold forging step, since the projected stem portion 4a of the blank 4 (see FIG. 1(d)) formed in the third cold forging step is inserted into the straight hole portion 72 of the fixed punch 45, it is possible to form or upset the enlarged head portion 5c into a predetermined shape with the buckling of the blank being reduced or avoided.

[0099] On the other hand, the enlarged head portion 5c of the fourth blank 5 (see FIG. 1(e)) is heated by a heating means. Then, in the subsequent hot forging process, the enlarged head portion 5c is more enlarged in the outer diameter and formed into a predetermined-shaped valve head portion 6a. Accordingly, it is possible to make an engine valve 6 having a greater ratio of the valve head to the valve stem, or an engine valve 6 having the larger-diameter valve head portion 6a and the smaller-diameter valve stem portion 6b (see FIG. 1(f)). Therefore, it is possible to improve the intake/exhaust efficiency of the engine by increasing the valve head diameter 6aD, and to provide an engine valve 6 that allows for improving the rapid responsiveness of the engine by reducing the weight or the diameter of the valve stem portion 6b.

[0100] In addition, the combination of the cold forging process and the hot forging process for making the engine valve 6 reduces the cost for making an engine valve 6 having a greater ratio of the diameter 6aD of the valve head portion 6a to the diameter 6bD of the valve stem portion 6b.

[0101] It is to be noted that the forming speed of the engine valve 6 by a conventional upset forging method is 4 to 10 engine valves per minute; and the forming speed of a conventional hot extrusion forging method is 12 to 20 engine valves per minute. In contrast, this embodiment of the present invention can mass produce 70 to 140 engine valves per minute, which is comparable with a conventional, fixed punch, cold and hot forging method.

[0102] It should also be noted that using the cold forging coil stock C reduces the material cost, as compared to using a round bar stock. For example, a round bar stock used for the upset forging method needs a process for grinding the surface of the round bar stock so as to acquire electric conductivity. The round bar stock also needs a wire-drawing process so as to thin the round bar stock. Accordingly, the round bar stock requires many manufacturing processes and higher material cost. Moreover, when the round bar stock is processed, many material fragments are generated, which results in a low manufacturing yield. In contrast, the cold forging coil stock C requires relatively few manufacturing processes, or low material cost. Few material fragments are generated, which results in a high manufacturing yield.

[0103] Moreover, a round bar stock requires more down time due to the frequent replacements of the stock with respect to the forging apparatus, while the cold forging coil stock C requires less down time due to the less frequent replacements of the stock. Accordingly, the cold forging coil stock C achieves better productivity than the round bar stock.

[0104] According to adopting the first to fourth cold forging steps, since the shape of the enlarged head portion 5c, or a so-called onion shape, is made stable, it is possible to improve the quality of the engine valve 6 (see FIG. 1 (f)) forged by the hot forging step in a subsequent process. For example, less variations can be made in the valve head diameter 6aD of the valve head portion 6a can be made than those of the conventional products so that the margin to be processed by a subsequent grinding process can be reduced.

[0105] According to the method for making the aforementioned engine valve 6 (see FIG. 1(f)), it is possible to make an engine valve 6 having a greater ratio of the valve head to the valve stem such as 6.9. FIG. 11 illustrates a relationship between the valve head diameter and the valve stem diameter of the engine valve, or a valve head to valve stem ratio. It should be noted that curve A shows a valve head to valve stem ratio of 7, curve B a valve head to valve stem ratio of 6, and curve C a valve head to valve stem ratio of 5.

[0106] As shown in FIG. 11, when an engine valve is made according to a conventional upset forging method; a hot extrusion method; a total cold forging method; or a fixed-punch cold and hot forging method, a valve head to valve stem ratio is limited to approximately 5 or to approximately 6, which is shown by the dots around curve B or C in FIG. 11. In contrast, according to the method of the present invention, it is possible to make an engine valve 6 having a larger valve head to valve stem ratio of approximately 7, which is shown by the dots around curve A in FIG. 11.

[0107] In addition, the following has been found by comparing the conventional total cold forging method with the method of the present invention.

[0108] Firstly, with respect to the materials, the total cold forging method is applicable for an alloy steel material of SCM435 inferior in heat resistance, which has a Vickers hardness number (Hv) of approximately 180. In contrast, the

method of the present invention can be used to form a heat resisting steel material of SUH11 or SUH3, which has a Vickers hardness number (Hv) in the range of 235 to 290.

[0109] Secondly, with respect to the valve head to valve stem ratio, the total cold forging method is applicable for making an engine valve having a valve head diameter of 25 mm and a valve stem diameter of 5.5, i.e. a valve head to valve stem ratio of 4.5. In contrast, the method of the present invention is applicable for making an engine valve having a valve head diameter of 38 mm and a valve stem diameter of 5.5 mm, i.e. a valve head to valve stem ratio of 6.9.

[0110] Thirdly, with respect to the valve face margin of the valve head 6a to be processed, the total cold forging method allows for a 1.2 mm diametral margin. In contrast, the method of the present invention allows for a 0.4 mm diametral margin.

[0111] Fourthly, with respect to the forging speed in the cold forging process, the total cold forging method allows for a speed of 1 second per engine valve. In contrast, the method of the present invention allows for a speed of 0.45 seconds per engine valve.

[0112] Fifthly, with respect to a forging die life, the total cold forging method has a useful life of 100,000 shots. In contrast, the method of the present invention allows for more than 250,000 shots.

[0113] Compared with the conventional total cold forging method, the method of the present invention has cut down the forging cost by approximately 15%.

[0114] The forging machine 30 (see FIG. 3) used for making the blank 4 having the enlarged head portion 4c also allows for the same benefits as described above.

[0115] With respect to the slide punch 37 of the forging machine 30, the tapered hole portion 76 of the die hole 71 of the inner punch 70 has a taper angle α that is set in the range of 6 to 20 degrees. Accordingly, it is possible to reduce or avoid a backward-movement failure of the slide punch 37 as well as a buckling of the blank during the upsetting and forming of the enlarged head portion 4c of the third blank 4.

[0116] Also, with respect to the slide punch 37 of the forging machine 30, the clearance between the straight hole portion 72 of the die hole 71 of the inner punch 70 and the pin body 60 of the punch pin 36 is set in the range of 2 to 5% of the stem diameter 61D of the main portion 61 of the pin body 60. Accordingly, it is possible to reduce or avoid a backward-movement failure of the slide punch 37 as well as plastic deformation of the pin body 60 of the punch pin 36 during the upsetting and forming of the enlarged head portion 4c of the third blank 4.

[0117] With respect to the inner punch 70, the ejection slope β is provided on the inner surface of the straight hole portion 76 of the die hole 71. The ejection slope β (see FIG. 7) is set in the range of 0.03 to 0.10 degrees. Accordingly, it is possible to reduce or avoid a backward-movement failure of the slide punch 37 as well as a buckling of the blank during the upsetting and forming of the enlarged head portion 4c of the third blank 4.

[0118] With respect to the punch pin 36 of the forging machine 30, the outer surface of the main portion 61, other than the distal end portion 62, has a diametral relief 63 (see FIG. 5) in the range of 0.1 to 0.5 mm. Accordingly, it is possible to reduce or avoid a backward-movement failure of the slide punch 37 as well as plastic deformation of the pin body 60 of the punch pin 36 during the upsetting and forming of the enlarged head portion 4c of the third blank 4.

[0119] The present invention has been described in detail with particular reference to certain preferred embodiments thereof, but it should be understood that the present invention is not to be limited to the disclosed embodiment, variations and modifications can be effected within the subject matter of the invention.

It is explicitly stated that all features disclosed in the description and/or the claims are intended to be disclosed separately and independently from each other for the purpose of original disclosure as well as for the purpose of restricting the claimed invention independent of the composition of the features in the embodiments and/or the claims. It is explicitly stated that all value ranges or indications of groups of entities disclose every possible intermediate value or intermediate entity for the purpose of original disclosure as well as for the purpose of restricting the claimed invention, in particular as limits of value ranges.

REFERENCE NUMERALS

[0120]

1	Blank
2	First blank
2a, 3a	Main stem portion
2b, 3b, 4d, 5d	Diameter-reducing stem portion
2c, 4a, 5a	Projected stem portion
2d, 3d,	Rounded area
3	Second blank
3c, 4e, 5e	Smaller-diameter stem portion
4	Third blank
4b, 5b	Tapered portion

4c, 5c	Enlarged head portion
5	Fourth blank (elongated product)
6	Engine valve (product)
6a	Valve head portion
5 6b	Valve stem portion
10, 20, 30, 40	Forging machine
36, 46	Punch pin
37	Slide punch
38	Spring member
10 39	Engagement tube
45	Fixed punch
45a	Die hole
45b, 72	Straight hole portion
45c, 76	Tapered hole portion
15 60	Pin body
62	Distal end portion of the punch pin
70	Inner punch
71	Die hole
SP	Slide punch mechanism
20	

Claims

1. A method for making an elongated product (5) having an enlarged head portion (5c), **characterized in that** the method comprises the steps of:

(i) providing a first cold forging machine (10) so as to form on one end of an elongated blank (1) a diameter-reducing stem portion (2b), the diameter of which is made gradually smaller from the other end to the one end of the elongated blank (1);

(ii) providing a second cold forging machine (20) so as to form on one end of the blank (2) processed by the step (i) a smaller-diameter stem portion (3c) with a predetermined length (3cL), the diameter of the smaller-diameter stem portion (3c) is made smaller than the diameter of the other end of the blank (2), ;

(iii) providing a third cold forging machine (30) so as to form on the other end of the blank (3) processed by the step (ii) an enlarged head portion (4c), the outer diameter (4cD) of which is enlarged; and

(iv) providing a fourth cold forging machine (40) so as to form the enlarged head portion (4c) of the blank (4) processed by the step (iii) into a predetermined shape (5c), wherein:

the third cold forging machine (30) has a slide punch mechanism (SP) including a punch pin (36) that can press the other end face of the blank (3), a slide punch (37) that has a die hole (71) into which the punch pin (36) and the other end of the blank (3) are inserted, and a spring member (38) biasing the slide punch (37) in the pressing direction;

the die hole (71) includes a straight hole portion (72) into which the punch pin (36) is inserted with a predetermined clearance, and a tapered hole portion (76) that is continued from the straight hole portion (72), has an entrance (73) for the blank (3), and increases in the clearance toward the entrance (73); and

the third cold forging machine (30) is constructed so as to form the enlarged head portion (4c) by the pressing force of the punch pin (36) in such condition that the slide punch (37) is engaged with the other end of the blank (3), and is also constructed so that the slide punch (37) moves backward against the biasing force of the spring member (38) by the pressure (P) applied to the slide punch (37) when the enlarged head portion (4c) is being enlarged.

2. The method as in claim 1, **characterized in that**

the step (iii) further includes the step of forming at the other end of the blank (3) a projected stem portion (4a), which is projected from the enlarged head portion (4c) and engaged into the straight hole portion (72) of the slide punch (37), wherein:

the fourth cold forging machine (40) has a punch pin (46) that can press the other end face of the blank (4), and a fixed punch (45) including a die hole (45a) into which the punch pin (46) and the projected stem portion (4a) are inserted;

the die hole (45a) has a straight hole portion (45b) into which the punch pin (46) is inserted with a predetermined clearance, and a tapered hole portion (45c) that is continued from the straight hole portion (45b), has an entrance for the blank (4), and increases in the clearance toward the entrance; and
 5 the fourth cold forging machine (40) is constructed so as to form the enlarged head portion (4c) into a predetermined shape (5c) by the pressing force of the punch pin (46) in such condition that the fixed punch (45) is engaged with the other end of the blank (4).

3. A method for making an engine valve (6), **characterized in that** the method as in claim 1 or 2 further comprises the step of:

10 (v) heating the elongated product (5) having the enlarged head portion (5c), which is processed by the step (iv), by a heating means so that in the subsequent hot forging process the enlarged head portion (5c) is more enlarged in the outer diameter (5cD) and formed into a predetermined-shaped valve head portion (6a).

- 15 4. A forging machine (30) for forging an elongated blank (3) so as to form on the other end of the blank (3) an enlarged head portion (4c), the outer diameter (4cD) of which is made larger, **characterized in that** the forging machine (30) has a slide punch mechanism (SP) including:

20 a punch pin (36) that can press the other end face of the blank (3);
 a slide punch (37) that has a die hole (71) into which the punch pin (36) and the other end of the blank (3) are inserted; and
 a spring member (38) biasing the slide punch (37) in the pressing direction; wherein:

25 the die hole (71) includes a straight hole portion (72) into which the punch pin (36) is inserted with a predetermined clearance, and a tapered hole portion (76) that is continued from the straight hole portion (72), has an entrance (73) for the blank (3), and increases in the clearance toward the entrance (73); and
 the forging machine (30) is constructed so as to form the enlarged head portion (4c) by the pressing force of the punch pin (36) in such condition that the slide punch (37) is engaged with the other end of the blank (3), and are also constructed so that the slide punch (37) moves backward against the biasing force of the
 30 spring member (38) by the pressure (P) applied to the slide punch (37) when the enlarged head portion (4c) is being enlarged.

- 35 5. The forging machine (30) as in claim 4, **characterized in that** with respect to the slide punch (37) of the forging machine (30), the tapered hole portion (76) of the die hole (71) has a taper angle (α) that is set in the range of 6 to 20 degrees.

- 40 6. The forging machine (30) as in claim 4 or 5, **characterized in that** with respect to the slide punch (37) of the forging machine (30), the clearance between the straight hole portion (72) of the die hole (71) of the slide punch (70) and the punch pin (36) is set in the range of 2 to 5% with respect to the stem diameter (61D) of the punch pin (36).

7. The forging machine (30) as in any one of claims 4 to 6, **characterized in that** with respect to the slide punch (37), an ejection slope (β), which is set in the range of 0.03 to 0.10 degrees, is provided on the inner surface of the straight hole portion (76) of the die hole (71).

- 45 8. The forging machine (30) as in any one of claims 4 to 7, **characterized in that** the punch pin (36) includes a pin body (61) and a distal end portion (62), the outer surface of the pin body (61) being formed so as to have a diametral relief (63) in the range of 0.1 to 0.5 mm.

- 50 9. A method for making an engine valve (6), **characterized in that** the method comprises the steps of:

(i) cutting a blank (1) having a predetermined length (L_1) from a coil stock (C) of heat resting steel;
 (ii) cold forging the blank (1) into a first blank (2) having on one end a stem portion (2b) and on the other end a main portion (2a);
 (iii) cold forging the first blank (2) into a second blank (3) having on one end a stem portion (3c) and on the
 55 other end a main portion (3a);
 (iv) maintaining the main portion (3a) of the second blank (3) radially within a predetermined straight hole (72) so as to cold forge the second blank (3) into a third blank (4) having on one end a stem portion (4e) and on the other end an enlarged head portion (4c) and a projected stem portion (4a) that is projected axially from the

enlarged head portion (4c) toward the other end of the third blank (4);
 (v) maintaining the projected stem portion (4a) of the third blank (4) radially within a predetermined straight hole
 (45b) so as to cold forge the third blank (4) into a fourth blank (5) having on one end a stem portion (5e) and
 on the other end an enlarged head portion (5c), the outer diameter (5cD) of the enlarged head portion (5c) being
 made larger than the outer diameter (4cD) of the enlarged head portion (4c) of the third blank (4); and
 (vi) hot forging the fourth blank (5) into the engine valve (6) having on one end a valve stem portion (6b) and
 on the other end a valve head portion (6a).

- 10.** A method for cold forging an elongated blank (3) so as to form on the other end of the blank (3) an enlarged head
 portion (4c) that is subsequently to be hot forged into a valve head portion (6a) of an engine valve (6), **characterized**
in that the method includes the steps of:

inserting the other end of the blank (3) into a die hole (71) of a slide punch (37);
 inserting a punch pin (36) into the die hole (71) so as to press the other end face of the blank (3); and
 forming the enlarged head portion (4c) by the pressing force of the punch pin (36) in such condition that the
 slide punch (37) is engaged with the other end of the blank (3) and moves axially backward by the pressure (P)
 applied to the slide punch (37).

- 11.** The method as in claim 10, **characterized in that**
 the pressure (P) applied to the slide punch (37) is generated when the enlarged head portion (4c) pushes up the
 slide punch (37) on the inner surface of the die hole (71).

- 12.** An elongated blank (3) having an enlarged head portion (3c), **characterized in that** the elongated blank (3) is cold
 forged by the method as in claim 10 or 11.

- 13.** An engine valve (6) having a valve head portion (6a) and a valve stem portion (6b), **characterized in that** the engine
 valve (6) is made by the method as in claim 3 or 9.

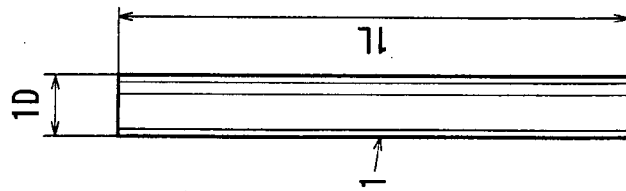


FIG. 1 (a)

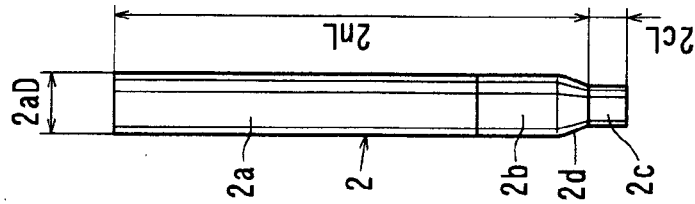


FIG. 1 (b)

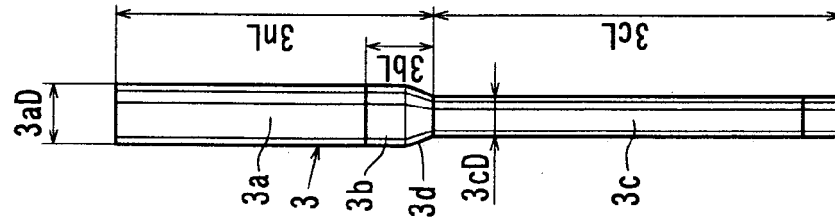


FIG. 1 (c)

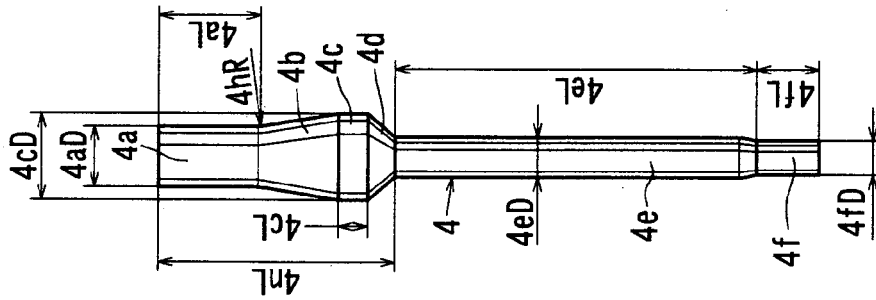


FIG. 1 (d)

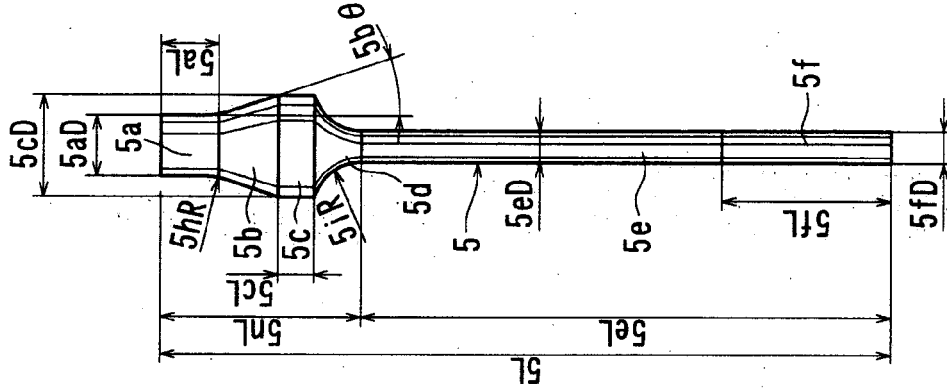


FIG. 1 (e)

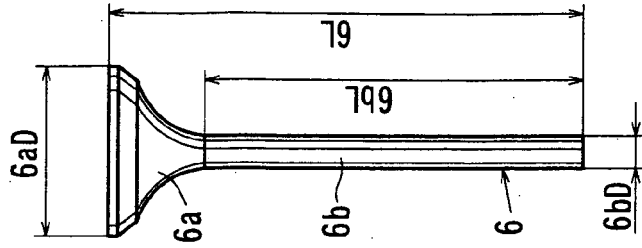


FIG. 1 (f)

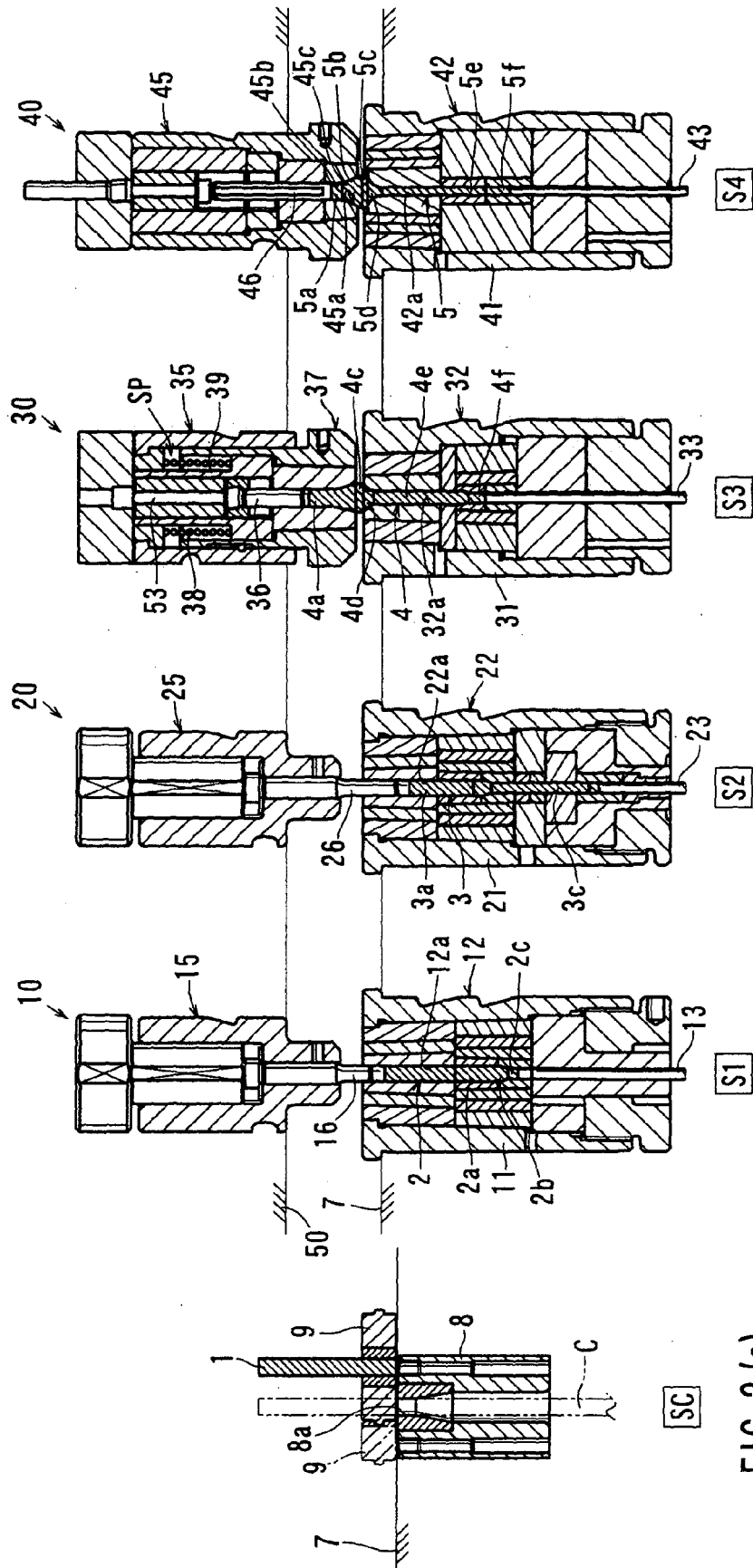


FIG. 2 (a)

FIG. 2 (b)

FIG. 2 (c)

FIG. 2 (d)

FIG. 2 (e)

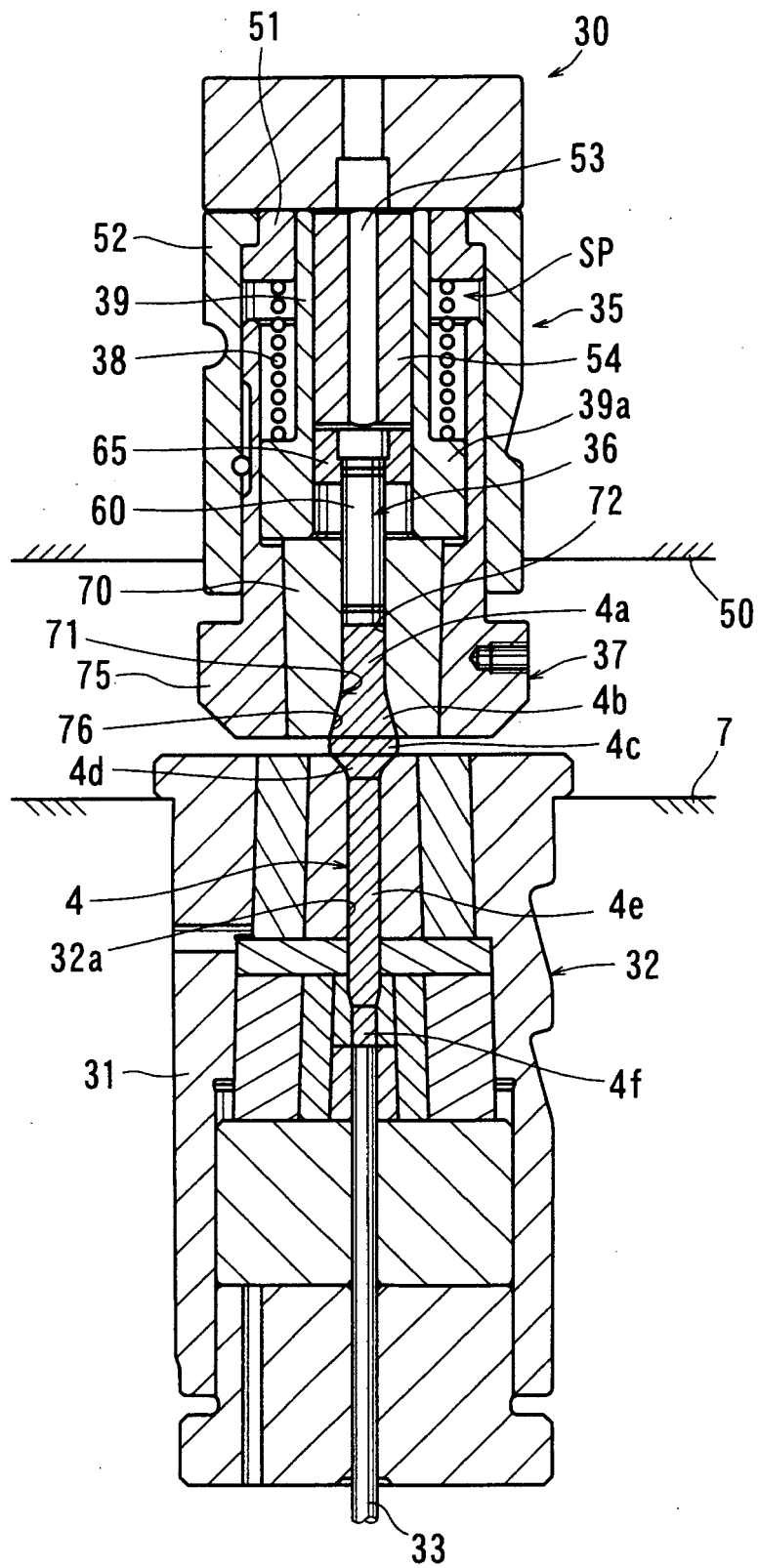


FIG. 3

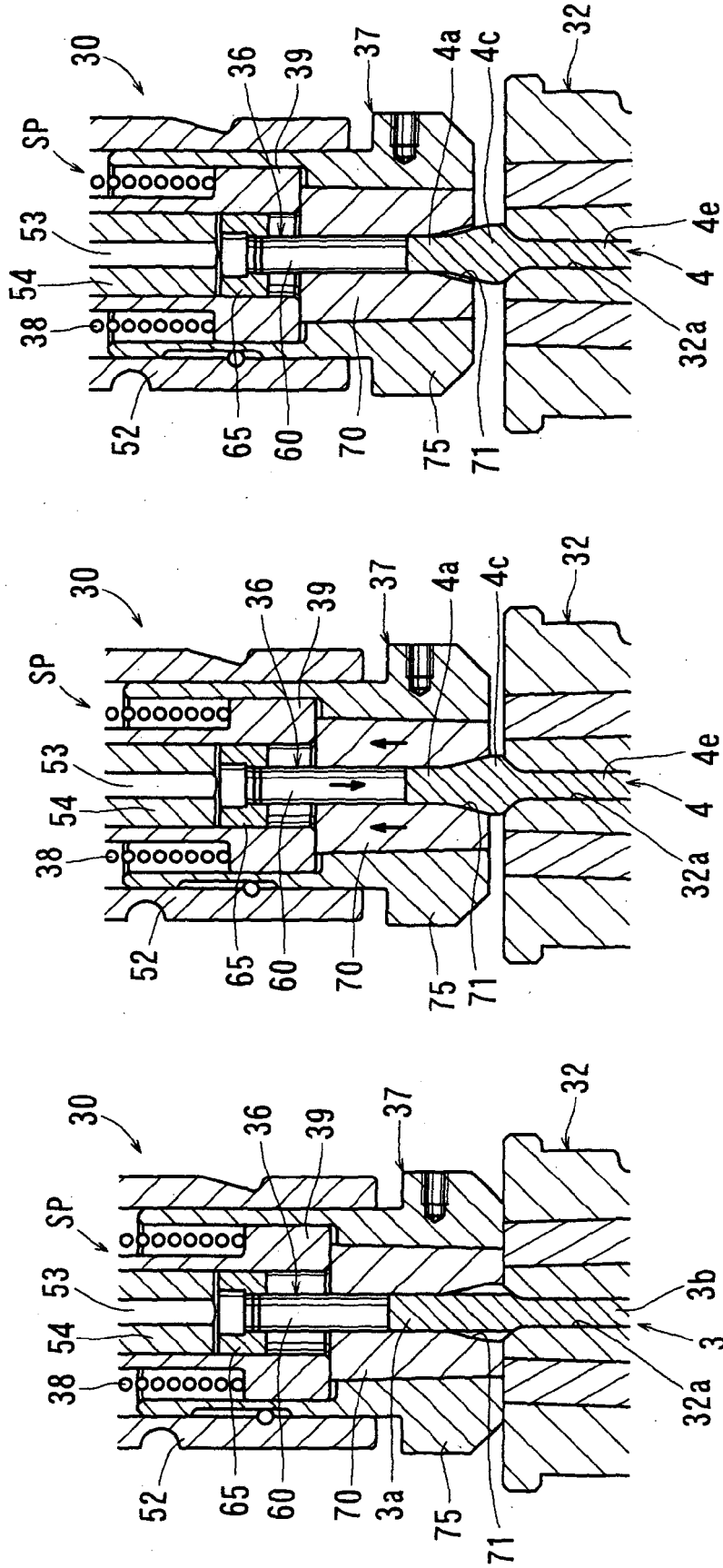


FIG. 4(a)

FIG. 4(b)

FIG. 4(c)

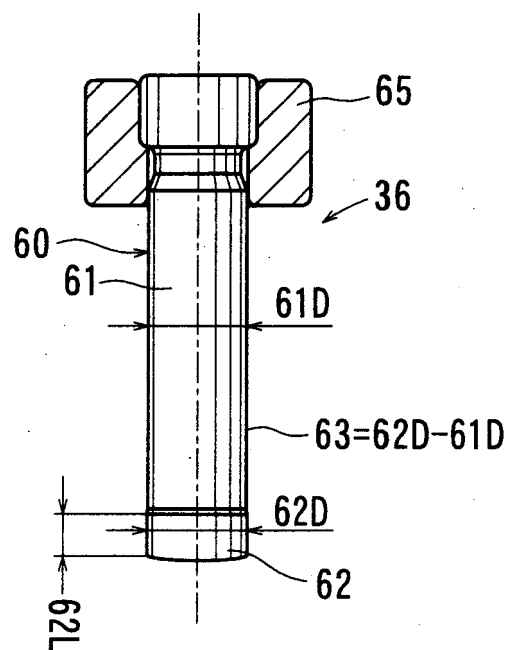


FIG. 5

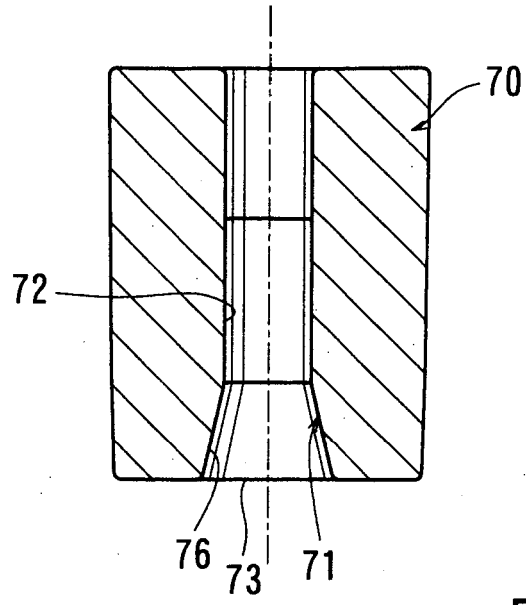


FIG. 6

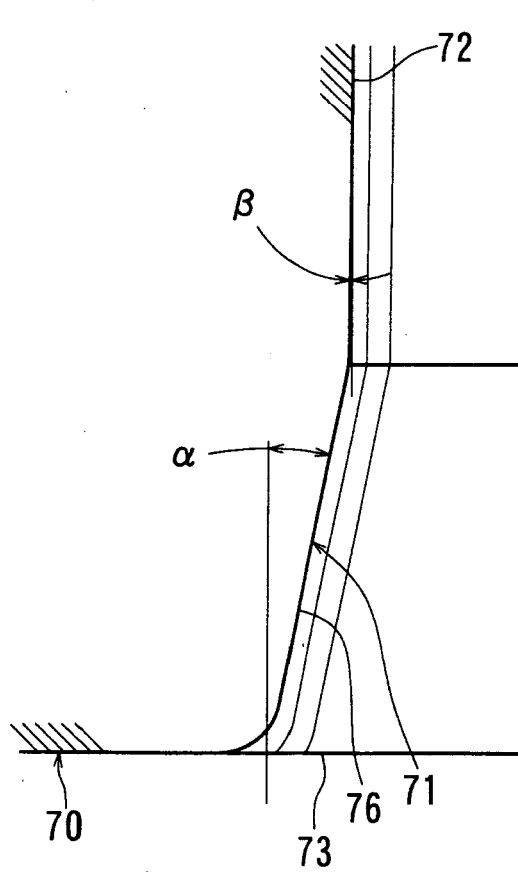


FIG. 7

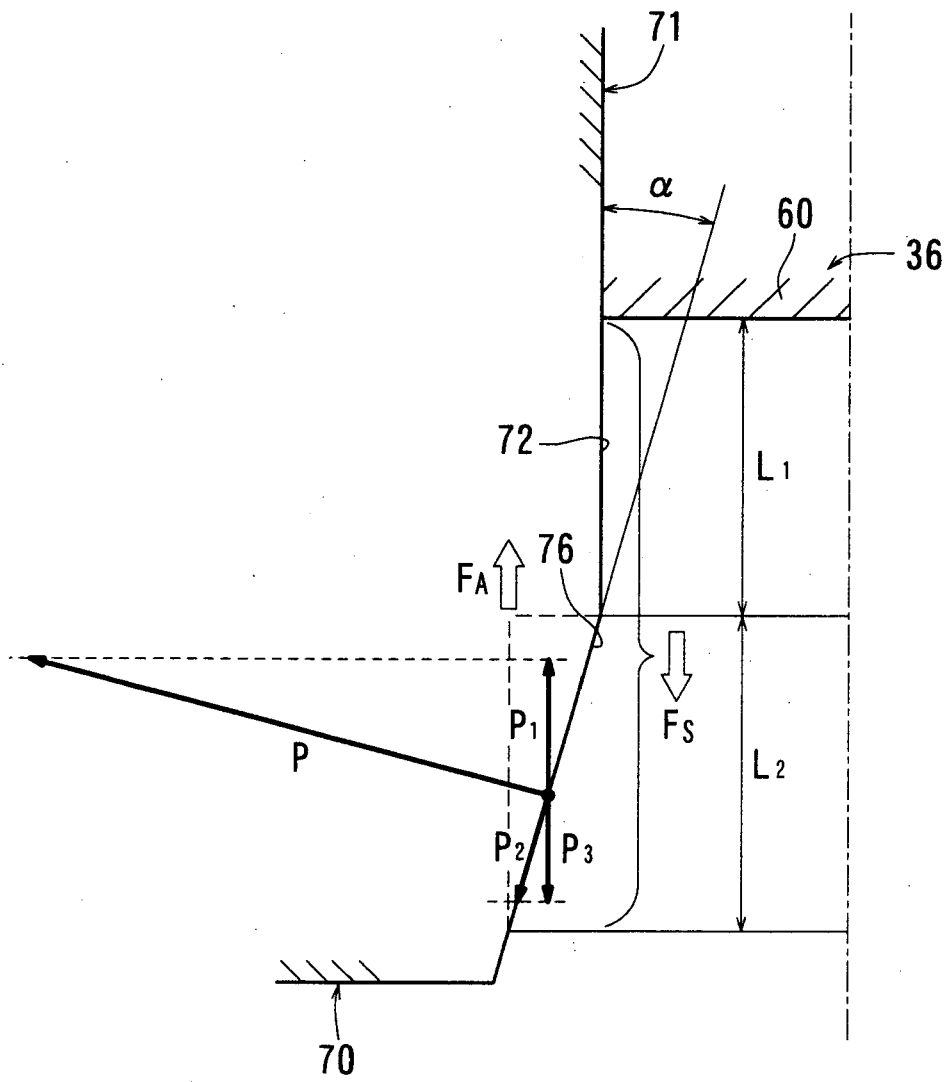


FIG. 8

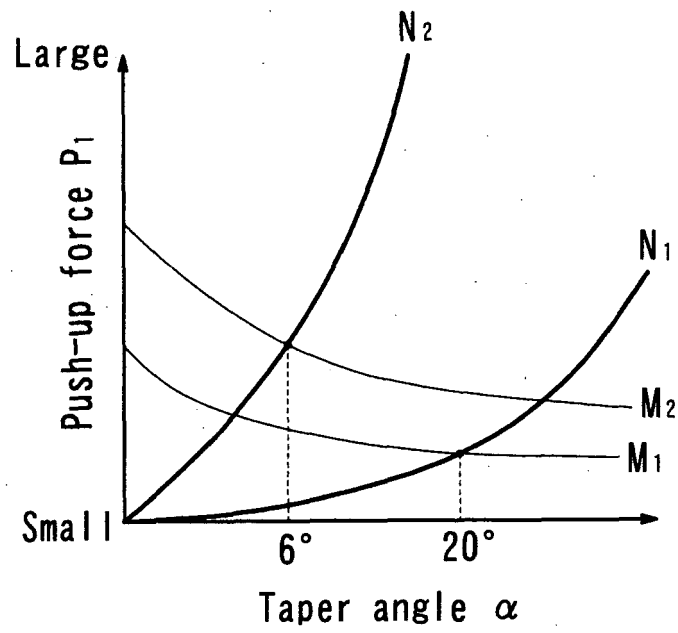


FIG. 9

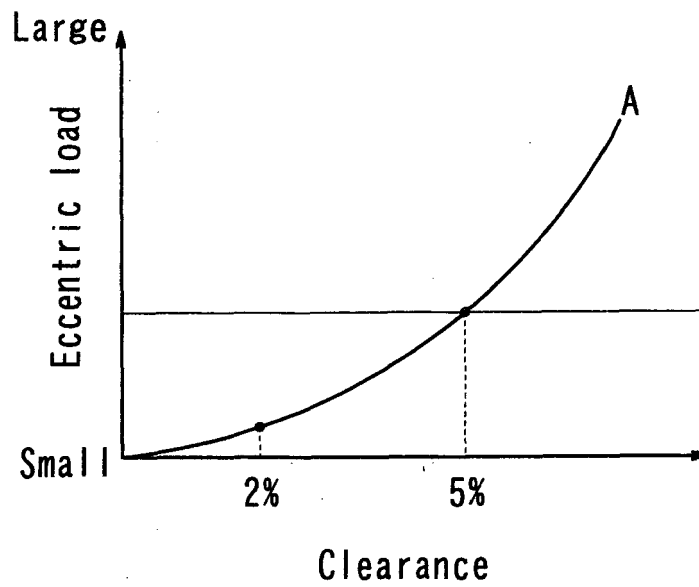


FIG. 10

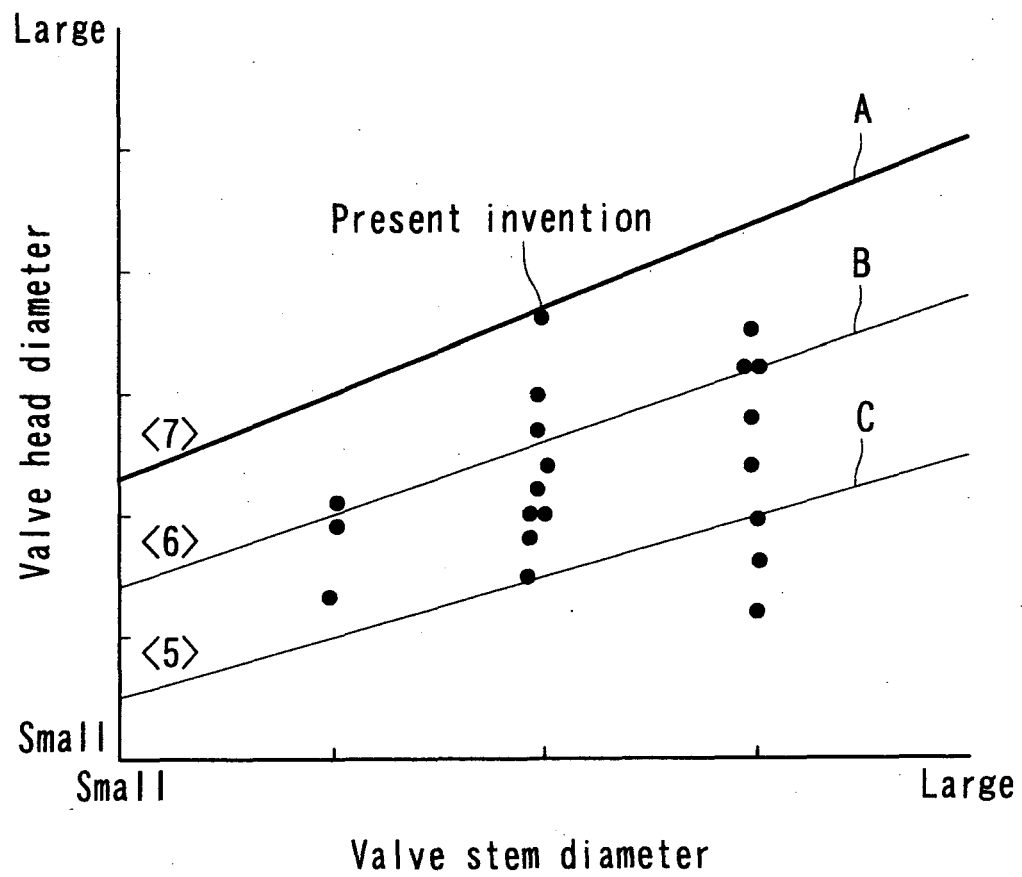


FIG. 11



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 05 02 0344

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 13 December 2005	Examiner Augé, M
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 05 02 0344

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