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(54) **DISTRIBUTION EXTRUDING FORMING DEVICE AND DISTRIBUTION EXTRUDING FORMING METHOD**

(57) A zoning closed-die extruding device may be provided. The device may comprise a closed female die (6) and a male die (9). The male die (9) is disposed in a longitudinal direction and configured to be mated with a closed cavity (61) of the closed female die (6) to extrude a blank. The male die (9) comprises an extruding shaft portion (92) and a stamp-extruding head portion (93) which is connected with the extruding shaft portion (92) and disposed below the extruding shaft portion (92). A cross-sectional area of the stamp-extruding head portion (93) perpendicular to a longitudinal axis of the closed female die (6) is smaller than that of the extruding shaft portion (92) perpendicular to the longitudinal axis of the closed female die (6). The male die (9) is configured to rotate about the longitudinal axis of the closed female die (6) so that the blank is sequentially and zonally deformed by the stamp-extruding head portion (93) inside the closed cavity (61) of the closed female die (6). A zoning closed-die extruding method is also provided. According to the present disclosure, the formed vessel has an even

wall thickness, a high reliability and a high strength, and cracks and defects of the vessel may be thoroughly closed and repaired.

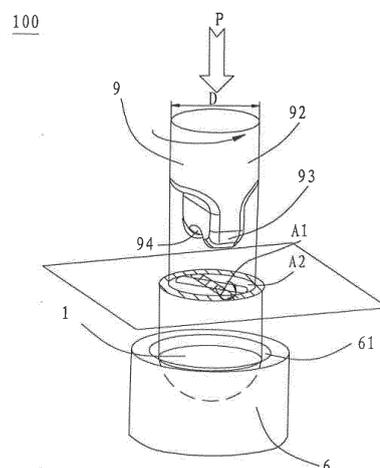


Fig. 6

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**Description****FIELD**

5 **[0001]** The present disclosure relates to the field of material processing, and more particularly to a zoning closed-die extruding device and a zoning closed-die extruding method.

**BACKGROUND**

10 **[0002]** Development of nuclear power has been one of the national strategic goals and national development tasks, and a pressure vessel for a nuclear reactor in a nuclear island urgently needs to be domestically manufactured. The pressure vessel for the nuclear reactor in Qinshan nuclear power station and Daya Bay nuclear power station, China, are imported from Alstom, France and Nippon Steel Corporation, which are very expensive. For the development of clean energy and the reduction of CO<sub>2</sub> emissions, by 2020, China plans to add 80 million KW of nuclear power installed capacity, and there is a need for about eighty one-million-KW class pressure vessels. The total price for eighty 0.4 million KW-class pressure vessels ranges from 40 billion yuan to 48 billion yuan. In China, self-manufacturing of the pressure vessel for the nuclear reactor needs to be urgently and quickly solved, which is a complex engineering and technical issue.

15 **[0003]** The nuclear reactor pressure vessel is usually manufactured by saddle forging, hollow ingot mandrel reaming, thick plate head pressing and girth welding etc. Since the Chernobyl nuclear accident in Soviet Union, longitudinal seam welding used for forming the nuclear reactor pressure vessel has been banned. Currently, the nuclear reactor pressure vessel is substantially manufactured by the saddle forging as shown in Fig. 1. Firstly, as shown in Fig. 1, five rings 100' are made, and then the five rings 100' are welded to form a straight cylinder portion of the pressure vessel. Then, a head 200' or 200" is formed by pressing or drawing a thick plate, as shown in Figs. 2-3. The straight cylinder portion and the head are welded, heat treated and processed to obtain the nuclear reactor pressure vessel 300', as shown in Fig. 4. However, this process involves many steps which are complex with low efficiency and low reliability. This is because, whether during the process of forming the ring 100' or during the process of forming the head 200' by pressing or drawing, the forming is not performed in a three-directional compressive stress state, and in the forming process, usually along with local tensile stress, there is a heavy potential risk for closure and restoration of cracks and defects.

20 **[0004]** In addition, currently, in a large number of nuclear power heavy-duty forging process, the change in the shape of an anvil, pressing and feeding processes etc. which are performed under a pressing force of 10,000 to 20,000 tons, may also not produce enough three-directional compressive stress and may also not reduce or eliminate the tensile stress. In addition, the deformation amount during the process is difficult to uniformize. Fig. 5 is a schematic view of a conventional rotary extruding press. As shown in Fig. 5, a circular blank 103" in Fig. 5 is forged by firstly lifting an upper male die 101" to a predetermined height, rotating the upper male die 101" by a certain angle and then lowering the upper male die 101" in a lower female die 102". However, it has been found through research that, in the open forging process, because extruding force is merely applied to materials in one direction as shown in Fig. 5 and the spherical tensor of stress only reaches about 80MPa, it is still difficult to close and restore cracks and defects in the deformed materials.

**SUMMARY**

25 **[0005]** The present disclosure is directed to solve at least one of the problems existing in the prior art. Accordingly, a zoning closed-die extruding method may need to be provided, by which a formed vessel may have an even wall thickness, a high reliability and a high strength, and cracks and defects in the vessel may be thoroughly closed and repaired. Further, a zoning closed-die extruding device may also need to be provided.

30 **[0006]** According to an aspect of the present disclosure, a zoning closed-die extruding device may be provided. The zoning closed-die extruding device may comprise: a closed female die; and a male die disposed in a longitudinal direction and configured to be mated with a closed cavity of the closed female die to extrude a blank, in which the male die comprises: an extruding shaft portion; and a stamp-extruding head portion connected with the extruding shaft portion and disposed below the extruding shaft portion, in which a cross-sectional area of the stamp-extruding head portion perpendicular to a longitudinal axis of the closed female die is smaller than that of the extruding shaft portion perpendicular to the longitudinal axis of the closed female die; and the male die is configured to rotate about the longitudinal axis of the closed female die so that the blank is sequentially and zonally by the stamp-extruding head portion inside the closed cavity of the closed female die.

35 **[0007]** In the zoning closed-die extruding device according to an embodiment of the present disclosure, by sequentially and zonally extruding the blank in the closed female die using the male die, metal may flow in a radial direction to form a bottom of the vessel and may rise along a generatrix of the vessel to form a cylindrical portion of the vessel, so that one-step forming of the cylinder body and the head of the vessel may be achieved without girth welding. Therefore, this

process may have reduced manufacturing steps with reduced complexity, shortened production period and enhance efficiency. In addition, because the metal is extruded in the closed female die using the male die, the blank is substantially deformed in a three-directional compressive stress state, the tensile stress during the deforming process may be reduced to a minimum extent or even eliminated, so that the vessel may have an even wall thickness with high reliability and strength, and cracks and defects etc. may be thoroughly closed and restored.

5 [0008] According to an embodiment of the present disclosure, the extruding shaft portion and the stamp-extruding head portion are integrally formed.

[0009] According to an embodiment of the present disclosure, the extruding shaft portion comprises: a cylindrical shaft portion; and a flange portion formed between a lower part of the cylindrical shaft portion and the stamp-extruding head portion, in which the cross-sectional area of the stamp-extruding head portion perpendicular to the longitudinal axis of the closed female die is smaller than that of the flange portion perpendicular to the longitudinal axis of the closed female die.

10 [0010] According to an embodiment of the present disclosure, the closed female die is a prestressed extrusion die, and an inner diameter of the closed cavity of the prestressed extrusion die is greater than a maximum radial dimension of the extruding shaft portion and the stamp-extruding head portion.

15 [0011] According to an embodiment of the present disclosure, a cross section of the stamp-extruding head portion in a plane perpendicular to the longitudinal axis of the closed female die is of a rectangle shape, a long edge of the rectangle equals to a diameter of the extruding shaft portion, and a ratio of a short edge of the rectangle to the long edge thereof ranges from about 0.05 to about 0.95.

[0012] According to an embodiment of the present disclosure, a ratio of the cross-sectional area of the stamp-extruding head portion to the cross-sectional area of the extruding shaft portion is within a range of about 0.1 to about 0.9. Then the blank may be sequentially and zonally deformed with the stamp-extruding head portion.

20 [0013] According to an embodiment of the present disclosure, during extruding, an extrusion force applied to the male die is adapted to a width of the stamp-extruding head portion and a diameter of the extruding shaft portion.

[0014] According to an embodiment of the present disclosure, the extrusion force is about 1000MN to about 1500MN.

25 [0015] According to an embodiment of the present disclosure, a central portion of the stamp-extruding head portion is formed with a recess portion.

[0016] According to another aspect of the present disclosure, a zoning closed-die extruding method may be provided. The zoning closed-die extruding method may comprise: (1) placing a blank formed with a central hole having a predetermined depth in a closed female die and heating the blank to a temperature suitable for closed die forging; and (2) sequentially and zonally extruding the blank in the closed female die using a male die which is rotated about a longitudinal axis of the closed female die, in which the male die comprises: an extruding shaft portion; and a stamp-extruding head portion connected with the extruding shaft portion and disposed below the extruding shaft portion, in which a cross-sectional area of the stamp-extruding head portion perpendicular to the longitudinal axis of the closed female die is smaller than that of the extruding shaft portion perpendicular to the longitudinal axis of the closed female die.

30 [0017] In the zoning closed-die extruding method according to an embodiment of the present disclosure, by sequentially and zonally extruding the blank in the closed female die using the male die, a metal may flow in a radial direction to form a bottom of the vessel and may rise along a generatrix of the vessel to form a cylindrical portion of the vessel, so that one-step forming of the cylinder body and the head of the vessel may be achieved without girth welding. Therefore, this process may have reduced manufacturing steps with reduced complexity, shortened production period and enhance efficiency. In addition, because the metal is extruded in the closed female die using the male die, the blank is substantially deformed in a three-directional compressive stress state, the tensile stress during the deforming process may be reduced to a minimum extent or even eliminated, so that the vessel may have an even wall thickness with high reliability and strength, and cracks and defects etc. may be thoroughly closed and restored.

35 [0018] According to an embodiment of the present disclosure, the step (2) comprises: (2.1) extruding the blank along the central hole using a predetermined extrusion force; (2.2) raising the male die for restoration; (2.3) rotating the male die about the longitudinal axis of the closed female die through a predetermined angle; and (2.4) repeating the step (2.1), (2.2) and (2.3).

40 [0019] According to an embodiment of the present disclosure, a central portion of the stamp-extruding head portion is formed with a recess portion.

45 [0020] According to an embodiment of the present disclosure, in the step (2), an extrusion force applied to the male die is adapted to a width of the stamp-extruding head portion and a diameter of the extruding shaft portion.

[0021] According to an embodiment of the present disclosure, the extruding shaft portion comprises: a cylindrical shaft portion; and a flange portion formed between a lower part of the cylindrical shaft portion and the stamp-extruding head portion, in which the cross-sectional area of the stamp-extruding head portion perpendicular to the longitudinal axis of the closed female die is smaller than that of the flange portion perpendicular to the longitudinal axis of the closed female die.

50 [0022] According to an embodiment of the present disclosure, the extrusion force is about 1000MN to about 1500MN.

55 [0023] According to an embodiment of the present disclosure, the zoning closed-die extruding method further comprises: (3) finishing an inner surface of the zonally extruded blank in the step (2) along the central hole of the blank using

a finishing extrusion shaft so that the blank has an even wall thickness.

[0024] According to an embodiment of the present disclosure, the step (2) and the step (3) are alternately performed to extrude the blank.

5 [0025] According to an embodiment of the present disclosure, the predetermined angle is within a range of about 10 degrees to about 120 degrees.

[0026] According to an embodiment of the present disclosure, the step (2) further comprises: finishing an inner surface of the zonally extruded blank along the central hole of the blank using a finishing extrusion shaft so that the blank has an even wall thickness.

10 [0027] According to an embodiment of the present disclosure, in the step (2), a pressing displacement is within a range of about 2mm to about 2000mm.

[0028] According to an embodiment of the present disclosure, a pressing displacement every time in the step (3) is 0.01 times to 0.5 times as large as that in the step (2).

15 [0029] According to an embodiment of the present disclosure, a downward extrusion speed of the stamp-extruding head portion is within a range of about 5mm/s to about 90mm/s when the blank is made of a ferrous metal, or within a range of about 20mm/s to about 300mm/s when the blank is made of a nonferrous metal.

[0030] According to an embodiment of the present disclosure, the closed female die is a prestressed extrusion die, and an inner diameter of the closed cavity of the prestressed extrusion die is greater than a maximum radial dimension of the extruding shaft portion and the stamp-extruding head portion.

20 [0031] According to an embodiment of the present disclosure, the central hole with the predetermined depth is formed by closed upsetting, impressing and hot piercing the blank in the closed female die respectively.

[0032] According to an embodiment of the present disclosure, the extruding shaft portion and the stamp-extruding head portion are integrally formed.

25 [0033] According to an embodiment of the present disclosure, the closed female die is a prestressed extrusion die, and an inner diameter of the closed cavity of the prestressed extrusion die is greater than a maximum radial dimension of the extruding shaft portion and the stamp-extruding head portion.

[0034] According to an embodiment of the present disclosure, a cross section of the stamp-extruding head portion is of a rectangle shape, a long edge of the rectangle equals to a diameter of the extruding shaft portion, and a ratio of a short edge of the rectangle to the long edge thereof is within a range of about 0.05 to about 0.95.

30 [0035] According to an embodiment of the present disclosure, a ratio of the cross-sectional area of the stamp-extruding head portion to the cross-sectional area of the extruding shaft portion is within a range of about 0.1 to about 0.9.

[0036] The zoning closed-die extruding method according to an embodiment of the present disclosure may also be used for forming a high-pressure or ultrahigh-pressure vessel with a high reliability and a large volume such as a nuclear evaporator, a hydrogenation reactor or a large-volume natural gas high-pressure vessel.

35 [0037] Additional aspects and advantages of the embodiments of the present disclosure will be given in part in the following descriptions, become apparent in part from the following descriptions, or be learned from the practice of the embodiments of the present disclosure.

## BRIEF DESCRIPTION OF THE DRAWINGS

40 [0038] These and other aspects and advantages of the disclosure will become apparent and more readily appreciated from the following descriptions taken in conjunction with the drawings in which:

Fig. 1 is a perspective view of a straight cylinder portion for manufacturing a conventional pressure vessel;

Fig. 2 is a sectional view of a head of a conventional pressure vessel manufactured by pressing;

45 Fig. 3 is a sectional view of a head of a conventional pressure vessel manufactured by drawing;

Fig. 4 is a schematic view of a conventional nuclear reactor pressure vessel;

Fig. 5 is a schematic view of a conventional rotary extruding press;

Fig. 6 is a perspective view of a zoning closed-die extruding device according to an embodiment of the present disclosure;

50 Fig. 7 is a front view of a male die in a zoning closed-die extruding device according to an embodiment of the present disclosure;

Fig. 8 is a left view of a male die in a zoning closed-die extruding device according to an embodiment of the present disclosure;

55 Fig. 9 shows a zonally extruding step in a zoning closed-die extruding method according to an embodiment of the present disclosure;

Fig. 10 shows a finishing step in a zoning closed-die extruding method according to an embodiment of the present disclosure;

Fig. 11 is a schematic view of a blank in a zoning closed-die extruding method according to an embodiment of the

present disclosure;

Fig. 12 shows that a blank is upset in a zoning closed-die extruding method according to an embodiment of the present disclosure;

Fig. 13 shows that a blank is impressed in a zoning closed-die extruding method according to an embodiment of the present disclosure;

Fig. 14 shows that a blank is hot pierced in a zoning closed-die extruding method according to an embodiment of the present disclosure; and

Fig. 15 shows that the blank is reamed after the hot piercing step shown in Fig. 14.

## DETAILED DESCRIPTION

**[0039]** Embodiments of the present disclosure will be described in detail in the following descriptions, examples of which are shown in the accompanying drawings, in which the same or similar elements and elements having same or similar functions are denoted by like reference numerals throughout the descriptions. The embodiments described herein with reference to the accompanying drawings are explanatory and illustrative, which are used to generally understand the present disclosure. The embodiments shall not be construed to limit the present disclosure.

**[0040]** The inventive concept of the present disclosure is that, by largely increasing a pressing force and under the constraint of a die, a zoning closed-die extruding method is used to increase a three-directional compressive stress, reduce and eliminate a tensile stress, and increase and uniformize deformation amount, thus closing and repairing or restoring cracks and defects and enhancing the reliability and the strength of a vessel. In addition, in a deforming method and die according to an embodiment of the present disclosure, the optimum condition for metal flowing and segregation eliminating may be created.

**[0041]** It should be noted that, as used herein, the term "zoning extruding" means that material is extruded sequentially in a chamber or cavity region by region, neighboring or non-neighboring and finally the material is sequentially deformed by a plurality of sub-region or local deformations.

**[0042]** In the deforming process of the material, a spherical tensor  $\sigma_m$  of stress is usually used as a quantitative indicator of a crack closing and/or soldering probability after the material is deformed.

**[0043]** Particularly, in a deformed piece, a stress tensor  $\sigma_{ij}$  at any point may be a sum of two tensors, i.e., a spherical tensor of stress  $\sigma_m$  and a deviatoric tensor of stress  $S_{ij}$ .

**[0044]** The stress tensor  $\sigma_{ij}$  is represented by a formula:

$$\sigma_{ij} = \sigma_m \delta_{ij} + S_{ij}$$

$$\begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix} = \begin{bmatrix} \sigma_m & 0 & 0 \\ 0 & \sigma_m & 0 \\ 0 & 0 & \sigma_m \end{bmatrix} + \begin{bmatrix} \sigma_x - \sigma_m & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y - \sigma_m & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z - \sigma_m \end{bmatrix}$$

**[0045]** According to an embodiment of the present disclosure, by sequentially and zonally extruding a blank in a closed female die, a large and even spherical tensor of stress  $\sigma_m$  may be provided, thus ensuring the closure of microscopic defects and cracks, acquiring an optimum soldering condition and creating a superior thermo-mechanical coupling condition.

**[0046]** Hereinafter, a zoning closed-die extruding device and a zoning closed-die extruding method according to an embodiment of the present disclosure will be described in detail with reference to the drawings, in which Fig. 6 is a perspective view of a zoning closed-die extruding device 100 according to an embodiment of the present disclosure; Fig. 7 is a front view of a male die 9 in a zoning closed-die extruding device 100 according to an embodiment of the present disclosure; and Fig. 8 is a left view of a male die 9 in a zoning closed-die extruding device 100 according to an embodiment of the present disclosure.

**[0047]** According to an embodiment of the present disclosure, the zoning closed-die extruding device 100 may comprise: a closed female die 6; and a male die 9 disposed in a longitudinal direction and configured to be mated with a closed cavity 61 of the closed female die 6 to extrude a blank. The male die 9 may comprise: an extruding shaft portion 92; and a stamp-extruding head portion 93 connected with the extruding shaft portion 92 and disposed below the extruding shaft portion 92, in which a cross-sectional area of the stamp-extruding head portion 93 perpendicular to a longitudinal axis of the closed female die 6 is smaller than that of the extruding shaft portion 92 perpendicular to the longitudinal axis

of the closed female die 6. According to an embodiment of the present disclosure, the male die 9 is configured to rotate about the longitudinal axis of the closed female die 6 so that the blank is sequentially and zonally deformed by the stamp-extruding head portion 93 inside the closed cavity 61 of the closed female die 6.

5 [0048] In the zoning closed-die extruding device 100 according to an embodiment of the present disclosure, by sequentially and zonally extruding the blank in the closed female die 6 using the male die 9, metal may flow in a radial direction to form a bottom of the vessel and may rise along a generatrix of the vessel to form a cylindrical portion of the vessel, so that one-step forming of the cylinder body and the head of the vessel may be achieved without girth welding. Therefore, this process may have reduced manufacturing steps with reduced complexity, shortened production period and enhance efficiency.

10 [0049] In addition, because the metal is extruded in the closed female die 6 using the male die 9, the blank is substantially deformed in a three-directional compressive stress state, the tensile stress during the deforming process may be reduced to a minimum extent or even eliminated, so that the vessel may have an even wall thickness with high reliability and strength, and cracks and defects etc. may be thoroughly closed and restored or restored.

15 [0050] According to an embodiment of the present disclosure, the extruding shaft portion 92 and the stamp-extruding head portion 93 may be integrally formed. Alternatively, the extruding shaft portion 92 and the stamp-extruding head portion 93 may be separately formed, so that the stamp-extruding head portion 93 may be conveniently replaced to reduce the manufacturing cost of the male die 9. As shown in Fig. 8, the extruding shaft portion 92 may comprise: a cylindrical shaft portion 921; and a flange portion 922 formed between a lower part of the cylindrical shaft portion 921 and the stamp-extruding head portion 93, in which the cross-sectional area of the stamp-extruding head portion 93 perpendicular to the longitudinal axis of the closed female die 6 is smaller than that of the flange portion 922 perpendicular to the longitudinal axis of the closed female die 6. Therefore, during the forming process, only the flange portion 922 may contact with an inner surface of the blank to be extruded, thus reducing the metal deforming resistance during the forming process.

25 [0051] According to an embodiment of the present disclosure, the closed female die 6 may be a prestressed extrusion die, thus increasing the safety of the extruding process. An inner diameter of the closed cavity 61 of the prestressed extrusion die is greater than a maximum radial dimension of the extruding shaft portion 92 and the stamp-extruding head portion 93. The dimension difference may be designed and determined according to a piece to be extruded.

30 [0052] According to an embodiment of the present disclosure, a cross section of the stamp-extruding head portion 93 in a plane perpendicular to the longitudinal axis of the closed female die 6 is of a rectangle shape, a long edge of the rectangle equals to a diameter of the extruding shaft portion 92, and a ratio of a short edge of the rectangle to the long edge thereof is within a range of about 0.05 to about 0.95, which may be selected according to practical requirements.

[0053] According to an embodiment of the present disclosure, a ratio of the cross-sectional area of the stamp-extruding head portion 93 to the cross-sectional area of the extruding shaft portion 92 is within a range of about 0.1 to about 0.9. Therefore, the blank may be sequentially and zonally extruded using the stamp-extruding head portion 93.

35 [0054] According to an embodiment of the present disclosure, during the forming process, an extrusion force applied to the male die 9 is adapted to a width of the stamp-extruding head portion 93 and a diameter of the extruding shaft portion 92.

40 [0055] According to an embodiment of the present disclosure, the extrusion force is about 1000MN to about 1500MN, which is different from the deforming force of about 100MN to about 200MN used in the prior art. The extrusion force may be combined with the abovementioned zoning closed-die extruding device, thus providing a large extrusion stress to the blank during the forming process of the blank so as to eliminate microscopic crystal defects and the like during the deforming process.

45 [0056] According to an embodiment of the present disclosure, a central portion of the stamp-extruding head portion 93 is formed with a recess portion 94. In this way, during the extruding process of the male die 9, the three-directional compressive stress may be formed in the material received in the recess portion 94, as shown in Fig. 9. Therefore, the tensile stress during the forming process may be reduced to a minimum extent or even eliminated, so that the vessel may have an even wall with high reliability and strength, and cracks and defects etc. may be thoroughly closed and restored or repaired.

50 [0057] According to an embodiment of the present disclosure, the closed cavity 61 of the closed female die 6 may be circular, rectangular or elliptic, and a cross section of at least part of the extruding shaft portion 92 may be rectangular, polygonal or elliptic.

55 [0058] During the operation process of the zoning closed-die extruding device 100, because the cross-sectional area of the stamp-extruding head portion 93 is smaller than that of the extruding shaft portion 92, the extrusion force may be effectively reduced, the extruding efficiency may be enhanced, and the ratio of the cross-sectional area of the stamp-extruding head portion 93 to the cross-sectional area of the extruding shaft portion 92 may be in a function relation to the extrusion force. As described above, the cross section of the stamp-extruding head portion 93 is of a rectangle shape, the long edge of the rectangle equals to the diameter of the extruding shaft portion 92, a ratio of the short edge, i.e., the width, of the rectangle to the diameter of the extruding shaft portion 92 is in a function relation to the extrusion

force, the closed female die 6, the extruding shaft portion 92 and the stamp-extruding head portion 93 are coaxial, and the closed female die 6 may be a cylinder having an upper opening with an inner diameter larger than outer diameters of the extruding shaft portion 92 and the stamp-extruding head portion 93. In use, an upper end of the extruding shaft portion 92 is detachably fixed on a pressing device of an extruding press (not shown), and a lower end of the closed female die 6 is detachably fixed on a work table of the extruding press. Because the metal is sequentially and zonally extruded by the extruding shaft portion 92 and the stamp-extruding head portion 93 in the closed cavity 61 of the closed female die 6 under a huge three-directional compressive stress, the metal may flow in the radial direction to form the bottom of the vessel and may rise along the generatrix of the vessel to form the cylindrical portion of the vessel as shown in Fig. 9, so that one-step forming of the cylindrical vessel may be achieved. Moreover, the metal is extruded under the three-directional compressive stress, thus ensuring the strength of the vessel 1.

**[0059]** Hereinafter, a zoning closed-die extruding method according to an embodiment of the present disclosure will be described with reference to the drawings.

**[0060]** The zoning closed-die extruding method according to an embodiment of the present disclosure may comprise: (1) placing a blank formed with a central hole having a predetermined depth in a closed female die 6 and heating the blank to a temperature suitable for closed extruding; and (2) sequentially and zonally extruding the blank in the closed female die 6 using a male die 9 which is rotated about a longitudinal axis of the closed female die 6, in which the male die 9 comprises: an extruding shaft portion 92; and a stamp-extruding head portion 93 connected with the extruding shaft portion 92 and disposed below the extruding shaft portion 92, in which a cross-sectional area of the stamp-extruding head portion 93 perpendicular to the longitudinal axis of the closed female die 6 is smaller than that of the extruding shaft portion 92 perpendicular to the longitudinal axis of the closed female die 6. Herein, the male die 9 may be any one of the male dies 9 described above.

**[0061]** In the zoning closed-die extruding method according to an embodiment of the present disclosure, by sequentially and zonally extruding the blank in the closed female die 6 using the male die 9, a metal may flow in a radial direction to form a bottom 11 of the vessel and may rise along a generatrix of the vessel to form a cylindrical portion 12 of the vessel, so that one-step forming of the cylinder body and the head of the vessel may be achieved without girth welding. Therefore, this process may have reduced manufacturing steps with reduced complexity, shortened production period and enhance efficiency. In addition, because the metal is extruded in the closed female die 6 using the male die 9, the blank is substantially deformed in a three-directional compressive stress state, the tensile stress during the deforming process may be reduced to a minimum extent or even eliminated, so that the vessel may have an even wall with high reliability and strength, and cracks and defects etc. may be thoroughly closed and restored or repaired.

**[0062]** The blank 1 formed with the central hole having the predetermined depth will be described below with reference to the drawings, in which Fig. 11 is a schematic view of a blank 1 in a zoning closed-die extruding method according to an embodiment of the present disclosure, Fig. 12 shows that a blank 1 is upset in a zoning closed-die extruding method according to an embodiment of the present disclosure; Fig. 13 shows that a blank 1 is impressed in a zoning closed-die extruding method according to an embodiment of the present disclosure; Fig. 14 shows that a blank 1 is hot pierced in a zoning closed-die extruding method according to an embodiment of the present disclosure; and Fig. 15 shows that the blank 1 is reamed after the hot piercing step in Fig. 14.

**[0063]** Firstly, the refined blank 1 is provided and heated to a temperature suitable for closed extruding, for example, a temperature in a range of about 1050 Celsius degrees to about 1250 Celsius degrees. Then, according to practical requirements, a blank riser 2 is removed using a flame cutting method with oxygen-acetylene flame and the like. Sometimes, both the blank riser 2 and a bottom of the blank 1 need to be removed. However, whether the bottom of the blank 1 needs to be removed depends on the practical refining quality of the bottom of the blank 1.

**[0064]** Then, the blank 1 is upset, as shown in Fig. 12. In Fig. 12, the bottom of the blank 1 is formed with a centering portion 3. The blank 1 is placed on an upsetting die 4 while an arc-shaped protrusion 11 on the bottom of the blank 1 is just disposed in a centering groove 41 of the upsetting die 4, and then force is applied to an upper part of the blank 1 to upset the blank 1. In this way, the regular centering portion 3 is formed from the arc-shaped protrusion 11 on the bottom of the blank 1 while the blank 1 is upset. The blank 1 may be open or closed upset in an open or closed die respectively.

**[0065]** Then, the upset blank 1 may be impressed, as shown in Fig. 13. The blank 1 may be firstly centered using the centering portion 3 of the blank 1, and then an upper surface 13 of the blank 1 is stamped by a central punch 5 having a guiding device to form a central hole 12 having a predetermined depth and a predetermined diameter.

**[0066]** Then, the blank 1 formed with the central hole 12 is hot pierced. That is, the blank 1 formed with the central hole 12 is fitted in place in the closed female die 6. A first pecker 7 moves downwards to extrude the blank 1 while a center of the first pecker 7 is aligned with the central hole 12 in the upper surface 13 of the blank 1, so that the depth and the diameter of the central hole 12 in the upper surface 13 of the blank 1 are increased to predetermined values.

**[0067]** Then, the blank 1 is subjected to a sequential and zonal extruding. As shown in Fig. 6, the blank 1 is placed in the closed female die 6 and positioned using the centering portion 3 on the bottom of the blank 1, with the centering portion 3 on the bottom of the blank 1 facing down. The metal is extruded by the extruding shaft portion 92 and the stamp-extruding head portion 93 along the central hole 12 of the blank 1 under an extrusion force of about 1000MN to

about 1500MN so that the metal may flow in the radial direction to form the bottom 11 of the vessel and may rise along the generatrix of the vessel to form the cylindrical portion 12 of the vessel, and then the stamp-extruding head portion 93 moves upwards for restoration along with the extruding shaft portion 92 and is rotated radially by a predetermined angle  $\alpha$  along with the extruding shaft portion 92. Afterwards, the metal is extruded by the extruding shaft portion 92 and the stamp-extruding head portion 93 along the central hole 12 of the blank 1 again, and the above steps are repeated until an upper end face of an extruded blank formed from the blank 1 becomes flat. In each process step, the stamp-extruding head portion 93 is rotated through one predetermined angle  $\alpha$  along with the extruding shaft portion 92.

**[0068]** This process is as follows. The blank 1 is placed in the closed female die 6 and sequentially and zonally extruded by the extruding shaft portion 92 and the stamp-extruding head portion 93 repeatedly. After extruded by the stamp-extruding head portion 93, the metal substantially radially flows towards a direction away from the stamp-extruding head portion 93. According to the law of least resistance on metal flowing proposed by Ivan Gubkin, a former Soviet Union scholar, the metal flows most quickly in a position where a distance between the stamp-extruding head portion 93 and an inner wall of the central hole 12 of the blank 1 is largest. In this way, when the central hole 12 of the blank 1 is extruded by the stamp-extruding head portion 93, the flowing metal enters into a clearance between the closed female die 6 and the extruding shaft portion 92 to flow upwards along the generatrix of the vessel, so that the height of a part of the cylindrical portion 12 of the vessel at this position where the metal flows most quickly is larger than that of other parts of the cylindrical portion 12 of the vessel. Because the stamp-extruding head portion 93 is unidirectionally and successively rotated in the central hole 12 of the blank 1, and the stamp-extruding head portion 93 is rotated by the predetermined angle  $\alpha$  after each zoning extruding process step, so that the upper end of the extruded blank formed from the blank 1 finally becomes flat. Apparently, the smaller the predetermined angle  $\alpha$  by which the stamp-extruding head portion 93 is radially rotated, the smaller the height difference of the upper end of the extruded blank formed from the blank 1 is. A plurality of zoning extruding process steps constitutes one zoning extruding step. That is, one zoning extruding step comprises a plurality of zoning extruding process steps. A zoning extruding process step number =  $360/\text{the predetermined angle } \alpha$ .

**[0069]** After the above zoning extruding step, the blank 1 is finished accordingly as shown in Fig. 10. An inner surface of the extruded blank formed from the blank 1 is integrally extruded along the central hole 12 of the blank 1 using a finishing extrusion shaft 10 so that the inner cavity of the extruded blank formed from the blank 1 has a flat surface and the extruded blank has an even wall thickness. After raised and rotated properly, the finishing extrusion shaft 10 performs extruding again to eliminate the influence of the eccentricity of the finishing extrusion shaft 10 and enhance the finishing precision.

**[0070]** It should be noted that, the above zoning extruding step and the finishing step may be alternately performed until the height, the thickness and the end face flatness of the extruded blank formed from the blank 1 reach desired predetermined values.

**[0071]** According to an embodiment of the present disclosure, when the blank 1 is subjected to zoning extruding, a downward extrusion speed at which the blank 1 is extruded by the stamp-extruding head portion 93 along the central hole 12 of the blank 1 is associated with the kind of the material of the blank 1. For example, the downward extrusion speed of the stamp-extruding head portion 93 may be controlled to be within a range of about 5mm/s to about 90mm/s when the blank is made of a ferrous metal such as a high-temperature metal or an alloy steel. For another example, the downward extrusion speed of the stamp-extruding head portion 93 may be controlled to be within a range of about 20mm/s to about 300mm/s when the blank is made of a nonferrous metal such as aluminum or copper.

**[0072]** According to an embodiment of the present disclosure, when the stamp-extruding head portion 93 is not contacted with the metal, both a rising speed and a falling speed of the stamp-extruding head portion 93 may be within a range of about 90mm/s to about 300mm/s.

**[0073]** When the blank 1 is subjected to zoning extruding, the circumferential rotating angle  $\alpha$  is within a range of about 10 degrees to about 120 degrees.

**[0074]** According to an embodiment of the present disclosure, in the zoning extruding step, a pressing displacement is within a range of about 2mm to about 2000mm.

**[0075]** A pressing speed of the finishing extrusion shaft 10 and a rising speed and a falling speed of the finishing extrusion shaft 10 when the finishing extrusion shaft 10 is not contacted with the metal in the finishing step may be the same as a pressing speed of the stamp-extruding head portion 93 and the rising speed and the falling speed of the stamp-extruding head portion 93 when the stamp-extruding head portion 93 is not contacted with the metal in the zoning extruding step respectively, but a pressing displacement every time in the finishing step is 0.01 times to 0.5 times as large as that in the zoning extruding step.

**[0076]** According to an embodiment of the present disclosure, after the hot piercing step, a hot pierce reaming step may be further performed. That is, the deepened central hole 12 of the blank 1 is reamed by extruding the blank 1 downwards along the central hole 12 in the upper surface 13 of the blank 1 using a second pecker 8 having a radial diameter greater than that of the first pecker 7, thus facilitating the subsequent deforming of the blank 1, as shown in Fig. 15. It should be noted that, both the above hot piercing step and the above hot piercing reaming step may be

performed in the closed female cavity 6.

[0077] The zoning closed-die extruding method according to an embodiment of the present disclosure may also be used for forming a high-pressure or ultrahigh-pressure vessel with a high reliability and a large volume such as a nuclear evaporator, a hydrogenation reactor or a large-volume natural gas high-pressure vessel, for example, a water chamber head of a nuclear evaporator.

[0078] In all, in the zoning closed-die extruding device and the zoning closed-die extruding method according to an embodiment of the present disclosure, because a huge pressing force of about 1200MN to about 1500MN is provided and the constraint force is largely improved and a superior constraint (heavy extruding and closed upsetting/piercing) condition is provided when the metal is deformed, a large and even spherical tensor of stress  $\sigma_m$  (generally reaching about 300MPa to 400MPa) may be provided, thus ensuring the optimum condition for closing/soldering microscopic defects and cracks on the blank 1 and creating a superior thermo-mechanical coupling condition. In addition, by using the zoning closed-die extruding device and the zoning closed-die extruding method according to an embodiment of the present disclosure, the manufacturing efficiency may be tremendously enhanced, the rejection rate may be reduced, and the utilization rate of the material may be improved accordingly.

[0079] Reference throughout this specification to "an embodiment", "some embodiments", "one embodiment", "an example", "a specific examples", or "some examples" means that a particular feature, structure, material, or characteristic described in connection with the embodiment or example is included in at least one embodiment or example of the disclosure. Thus, the appearances of the phrases such as "in some embodiments", "According to an embodiment of the present disclosure", "in an embodiment", "an example", "a specific examples", or "some examples" in various places throughout this specification are not necessarily referring to the same embodiment or example of the disclosure. Furthermore, the particular features, structures, materials, or characteristics may be combined in any suitable manner in one or more embodiments or examples.

[0080] Although explanatory embodiments have been shown and described, it would be appreciated by those skilled in the art that changes, alternatives, and modifications may be made in the embodiments without departing from spirit and principles of the disclosure. Such changes, alternatives, and modifications all fall into the scope of the claims and their equivalents.

## Claims

### 1. A zoning closed-die extruding device, comprising:

a closed female die; and

a male die disposed in a longitudinal direction and configured to be mated with a closed cavity of the closed female die to extrude a blank, wherein the male die comprises:

an extruding shaft portion; and

a stamp-extruding head portion connected with the extruding shaft portion and disposed below the extruding shaft portion, in which a cross-sectional area of the stamp-extruding head portion perpendicular to a longitudinal axis of the closed female die is smaller than that of the extruding shaft portion perpendicular to the longitudinal axis of the closed female die; and

the male die is configured to rotate about the longitudinal axis of the closed female die so that the blank is sequentially and zonally deformed by the stamp-extruding head portion inside the closed cavity of the closed female die.

### 2. The zoning closed-die extruding device of claim 1, wherein the extruding shaft portion and the stamp-extruding head portion are integrally formed.

### 3. The zoning closed-die extruding device of claim 2, wherein the extruding shaft portion comprises:

a cylindrical shaft portion; and

a flange portion formed between a lower part of the cylindrical shaft portion and the stamp-extruding head portion, in which the cross-sectional area of the stamp-extruding head portion perpendicular to the longitudinal axis of the closed female die is smaller than that of the flange portion perpendicular to the longitudinal axis of the closed female die.

4. The zoning closed-die extruding device of claim 1, wherein the closed female die is a prestressed extrusion die, and an inner diameter of the closed cavity of the prestressed extrusion die is greater than a maximum radial dimension of the extruding, shaft portion and the stamp-extruding head portion.
- 5 5. The zoning closed-die extruding device of claim 1, wherein a cross section of the stamp-extruding head portion in a plane perpendicular to the longitudinal axis of the closed female die is of a rectangle shape, a long edge of the rectangle equals to a diameter of the extruding shaft portion, and a ratio of a short edge of the rectangle to the long edge thereof ranges from about 0.05 to about 0.95.
- 10 6. The zoning closed-die extruding device of claim 1, wherein a ratio of the cross-sectional area of the stamp-extruding head portion to the cross-sectional area of the extruding shaft portion is within a range of about 0.1 to about 0.9.
7. The zoning closed-die extruding device of claim 1, wherein during extruding, an extrusion force applied to the male die is adapted to a width of the stamp-extruding head portion and a diameter of the extruding shaft portion.
- 15 8. The zoning closed-die extruding device of claim 7, wherein the extrusion force is about 1000MN to about 1500MN.
9. The zoning closed-die extruding device of claim 1, wherein a central portion of the stamp-extruding head portion is formed with a recess portion.
- 20 10. A zoning closed-die extruding method, comprising:
- (1) placing a blank formed with a central hole having a predetermined depth in a closed female die and heating the blank to a temperature suitable for closed die forging; and
- 25 (2) sequentially and zonally extruding the blank in the closed female die using a male die which is rotatable about a longitudinal axis of the closed female die, wherein the male die comprises:
- an extruding shaft portion; and
- a stamp-extruding head portion connected with the extruding shaft portion and disposed below the extruding shaft portion, in which a cross-sectional area of the stamp-extruding head portion perpendicular to the longitudinal axis of the closed female die is smaller than that of the extruding shaft portion perpendicular to the longitudinal axis of the closed female die.
- 30 11. The zoning closed-die extruding method of claim 10, wherein the step (2) comprises:
- 35 (2.1) extruding the blank along the central hole using a predetermined extrusion force;
- (2.2) raising the male die for restoration;
- (2.3) rotating the male die about the longitudinal axis of the closed female die through a predetermined angle; and
- 40 (2.4) repeating the steps (2.1), (2.2) and (2.3).
12. The zoning closed-die extruding method of claim 10, wherein a central portion of the stamp-extruding head portion is formed with a recess portion.
13. The zoning closed-die extruding method of claim 10, wherein the extruding shaft portion comprises:
- 45 a cylindrical shaft portion; and
- a flange portion formed between a lower part of the cylindrical shaft portion and the stamp-extruding head portion, in which the cross-sectional area of the stamp-extruding head portion perpendicular to the longitudinal axis of the closed female die is smaller than that of the flange portion perpendicular to the longitudinal axis of the closed female die.
- 50 14. The zoning closed-die extruding method of claim 10, wherein in the step (2), an extrusion force applied to the male die is adapted to a width of the stamp-extruding head portion and a diameter of the extruding shaft portion.
- 55 15. The zoning closed-die extruding method of claim 14, wherein the extrusion force is about 1000MN to about 1500MN.
16. The zoning closed-die extruding method of claim 10, further comprising:

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(3) finishing an inner surface of the sequentially and zonally extruded blank in the step (2) along the central hole of the blank using a finishing extrusion shaft so that the blank has an even wall thickness.

- 5
17. The zoning closed-die extruding method of claim 16, wherein the step (2) and the step (3) are alternately performed to extrude the blank.
18. The zoning closed-die extruding method of claim 11, wherein the predetermined angle is within a range of about 10 degrees to about 120 degrees.
- 10
19. The zoning closed-die extruding method of claim 11, wherein the step (2) further comprises:
- finishing an inner surface of the sequentially and zonally extruded blank along the central hole of the blank using a finishing extrusion shaft so that the blank has an even wall thickness.
- 15
20. The zoning closed-die extruding method of claim 16, wherein in the step (2), a pressing displacement is within a range of about 2mm to about 2000mm.
21. The zoning closed-die extruding method of claim 20, wherein a pressing displacement every time in the step (3) is 0.01 times to 0.5 times as large as that in the step (2).
- 20
22. The zoning closed-die extruding method of claim 10, wherein a downward extrusion speed of the stamp-extruding head portion is within a range of about 5mm/s to about 90mm/s when the blank is made of a ferrous metal, or within a range of about 20mm/s to about 300mm/s when the blank is made of a nonferrous metal.
- 25
23. The zoning closed-die extruding method of claim 10, wherein the closed female die is a prestressed extrusion die, and an inner diameter of the closed cavity of the prestressed extrusion die is greater than a maximum radial dimension of the extruding shaft portion and the stamp-extruding head portion.
- 30
24. The zoning closed-die extruding method of claim 10, wherein the central hole with the predetermined depth is formed by closed upsetting, impressing and hot piercing the blank in the closed female die respectively.
25. The zoning closed-die extruding method of claim 10, wherein the extruding shaft portion and the stamp-extruding head portion are integrally formed.
- 35
26. The zoning closed-die extruding method of claim 10, wherein the closed female die is a prestressed extrusion die, and an inner diameter of the closed cavity of the prestressed extrusion die is greater than a maximum radial dimension of the extruding shaft portion and the stamp-extruding head portion.
- 40
27. The zoning closed-die extruding method of claim 10, wherein a cross section of the stamp-extruding head portion is of a rectangle shape, a long edge of the rectangle equals to a diameter of the extruding shaft portion, and a ratio of a short edge of the rectangle to the long edge thereof is within a range of about 0.05 to about 0.95.
- 45
28. The zoning closed-die extruding method of claim 10, wherein a ratio of the cross-sectional area of the stamp-extruding head portion to the cross-sectional area of the extruding shaft portion is within a range of about 0.1 to about 0.9.

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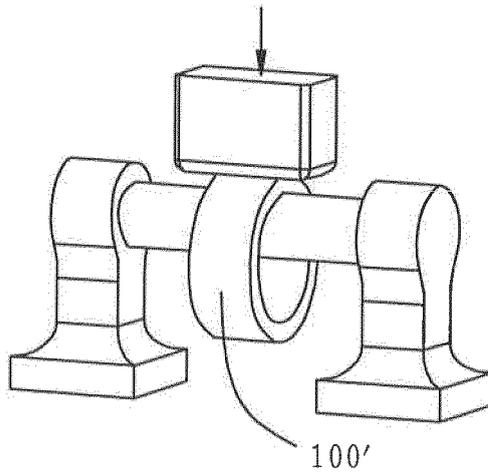


Fig. 1

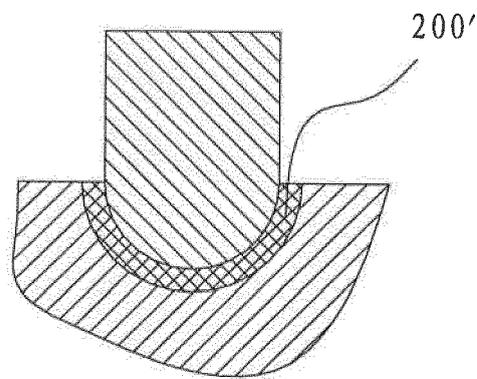


Fig. 2

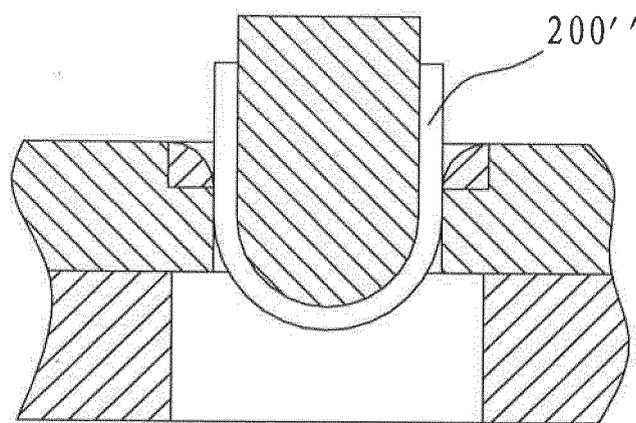


Fig. 3

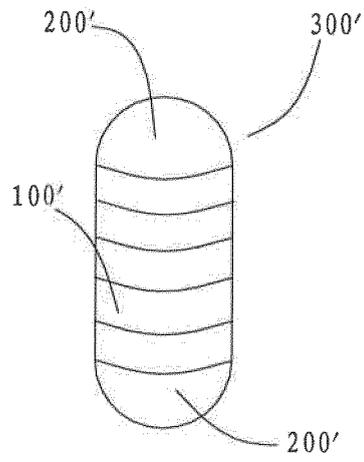


Fig. 4

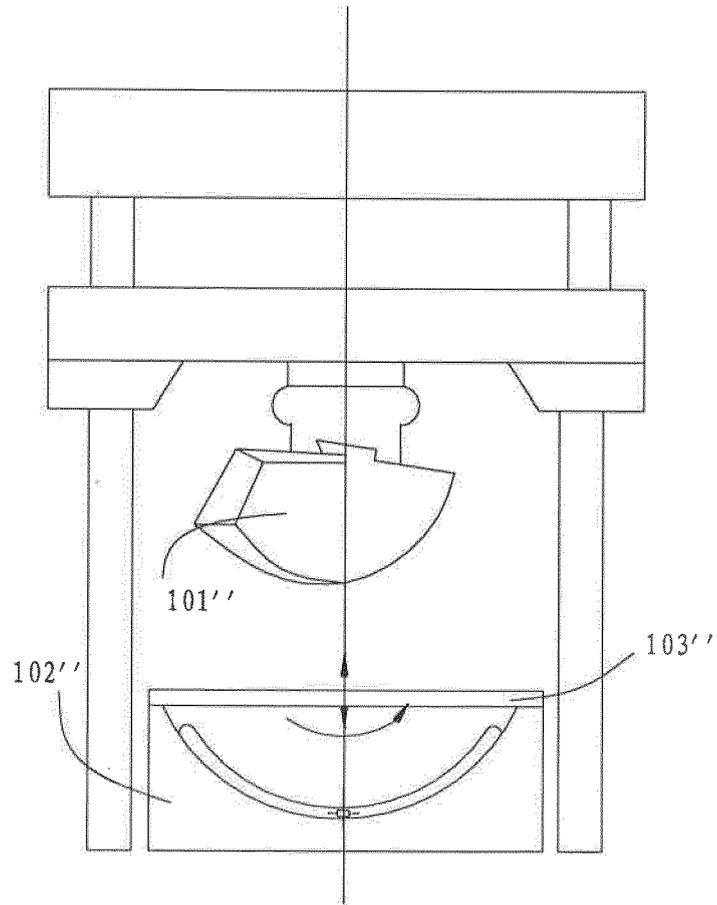


Fig. 5

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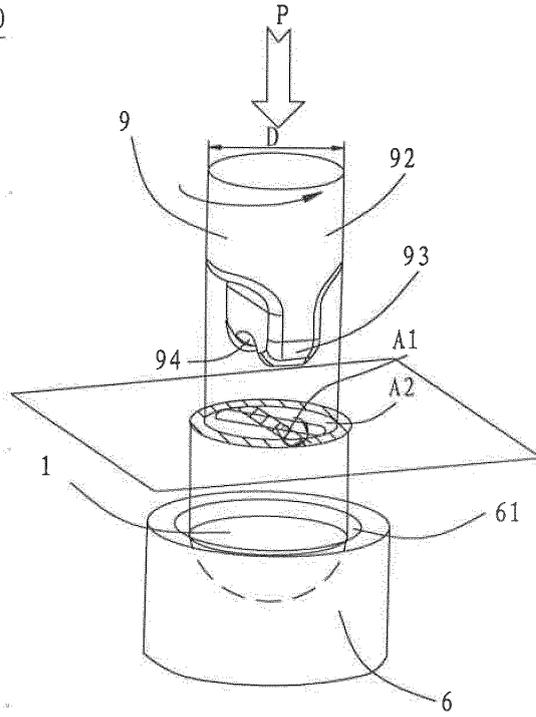


Fig. 6

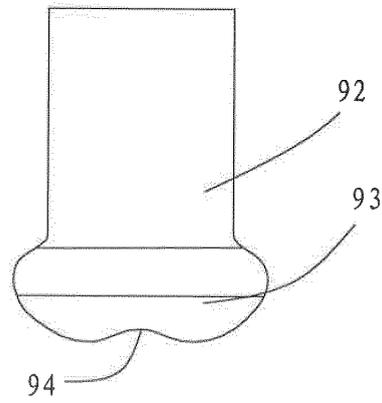


Fig. 7

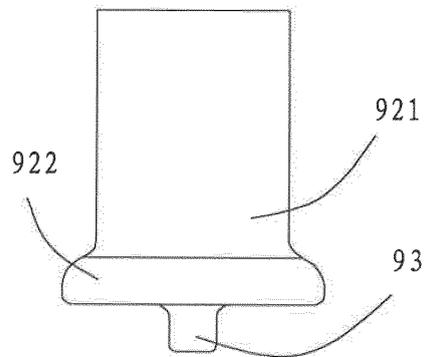


Fig. 8

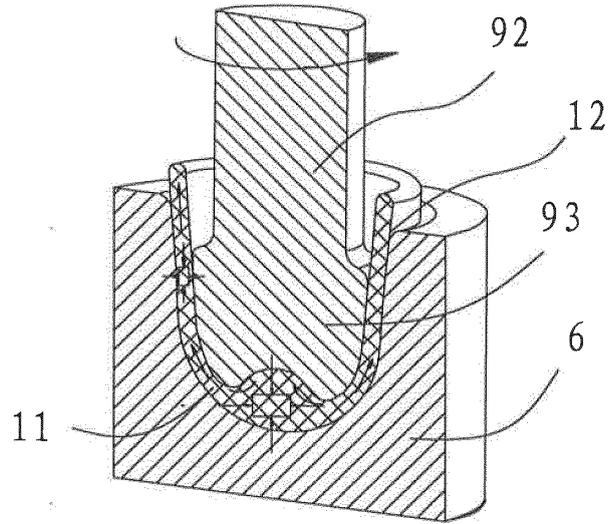


Fig. 9

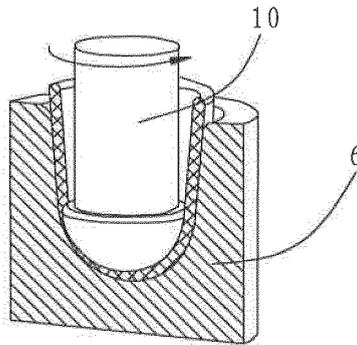


Fig. 10

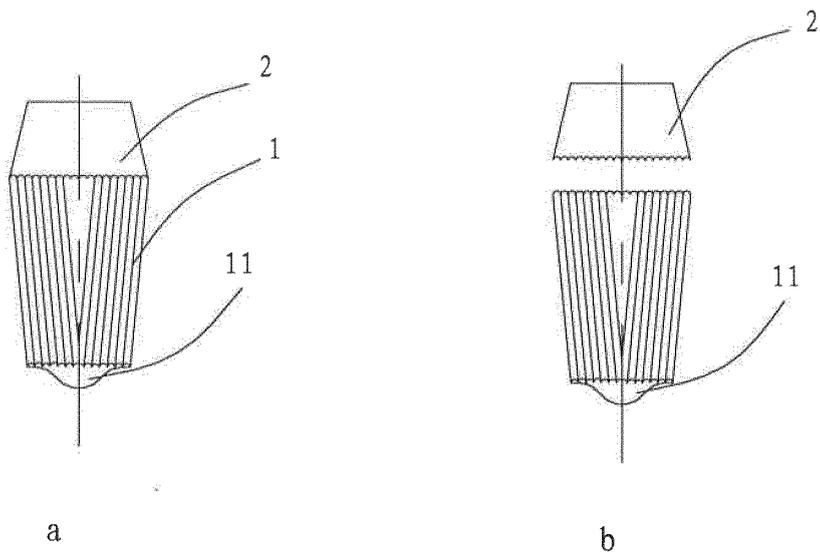


Fig. 11

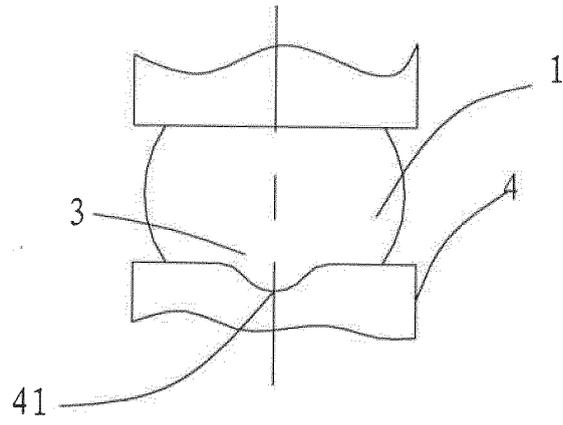


Fig. 12

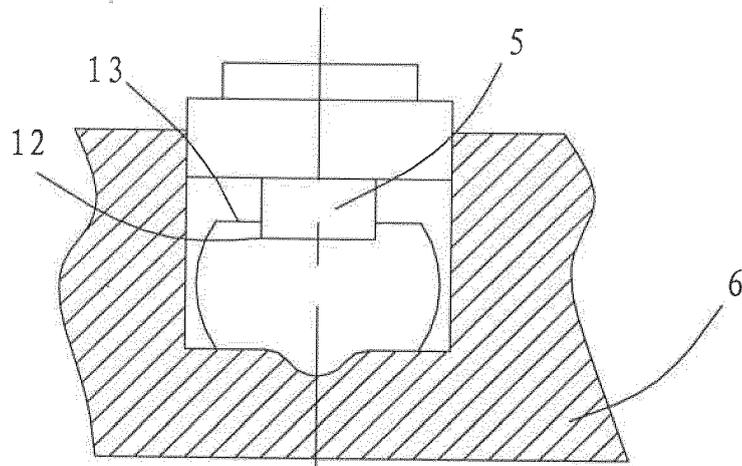


Fig. 13

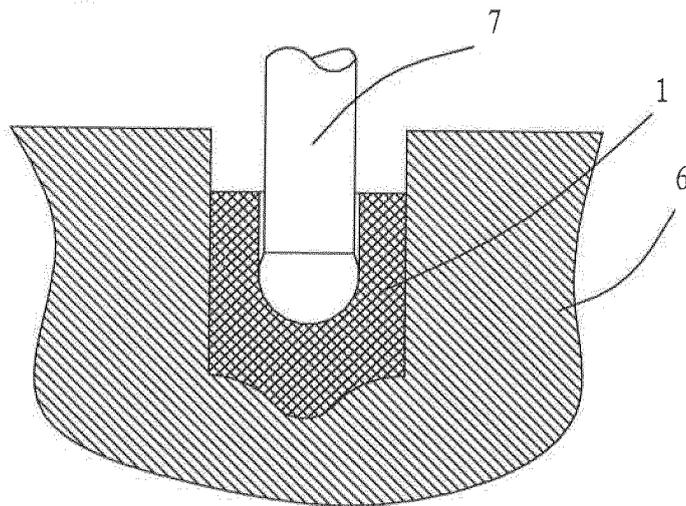


Fig. 14

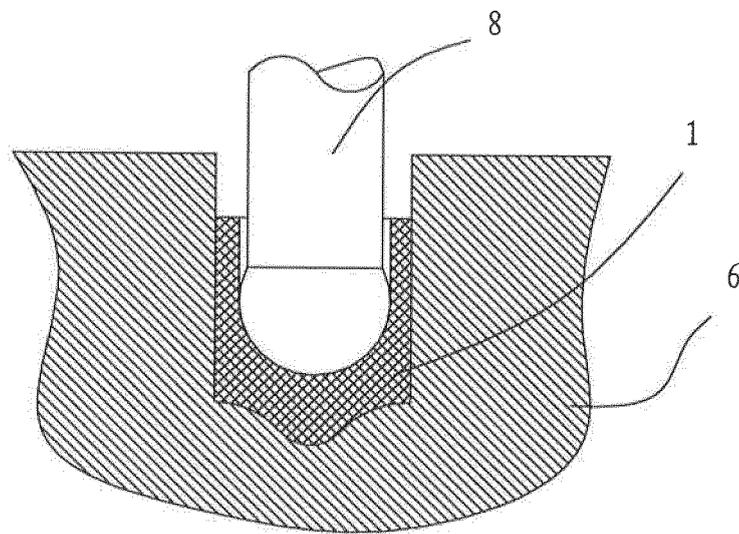


Fig. 15

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2010/074026

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>		
See extra sheet		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols)		
IPC: B21C23/-, B21J1/-, B21J5/-, B21J9/-, B21K21/-		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
WPI, EPODOC, CNPAT, CNKI: extrud+, forg+, stamp+, form+, upper w die, male w die, lower w die, female w die, mould, mold, rotat+, rectangle, rectangular		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A		
Y	CN1181721 A(ROINDEX OY LTD)13 May 1998(13.05.1998) See description, page 3, line 2-line 31, figures 1-2	3,13
Y	CN2841193 Y(CHINA NO 1 HEAVY MECHANICS CO)29 Nov.2006(29.11.2006) See description, page 2, line 1-line 17, figures 1,3	9,12,
Y	CN1166469 C(CHINA SECOND HEAVY MACHINERY G)15 Sep.2004 (15.09.2004) See claim 1, figures 2-7	10-26,28
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents:	“T”	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
“A” document defining the general state of the art which is not considered to be of particular relevance	“X”	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
“E” earlier application or patent but published on or after the international filing date	“Y”	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
“L” document which may throw doubts on priority claim (S) or which is cited to establish the publication date of another citation or other special reason (as specified)	“&”	document member of the same patent family
“O” document referring to an oral disclosure, use, exhibition or other means		
“P” document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search 25 Aug.2010(25.08.2010)	Date of mailing of the international search report <b>23 Sep. 2010 (23.09.2010)</b>	
Name and mailing address of the ISA/CN The State Intellectual Property Office, the P.R.China 6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China 100088 Facsimile No. 86-10-62019451	Authorized officer <b>LI, Xiaoli</b> Telephone No. (86-10)62085373	

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2010/074026

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Form PCT/ISA /210 (continuation of second sheet ) (July 2009)

**INTERNATIONAL SEARCH REPORT**  
 Information on patent family members

International application No.

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International application No.

PCT/CN2010/074026

Continuation of the second sheet A.

CLASSIFICATION OF SUBJECT MATTER:

B21C23/20 (2006.01) i

B21C25/02 (2006.01) i

B21J9/02 (2006.01) i

B21J1/04 (2006.01) i

B21K21/02 (2006.01) i