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(54) Casting method and mold design for optimization of material properties of a casting

(57) A casting method and mold design for optimization of material properties of a casting is disclosed, wherein the optimization is accomplished through control of a cooling rate of the casting to provide desired material properties throughout the casting. The apparatus and method are particularly useful in the casting of engine components such as engine blocks, cylinder heads and complex transmission components.

EP 1 852 198 A2

Description

FIELD OF THE INVENTION

[0001] The invention relates to casting and more particularly to a casting method and mold design for optimization of material properties of a casting, wherein the optimization is accomplished through control of a cooling rate of the casting.

BACKGROUND OF THE INVENTION

[0002] In a casting process, variations in material properties can occur in different regions within a casting. Amongst other reasons, the variations can occur when the different regions of the casting are permitted to cool, and thus solidify, at different rates. Castings having complicated geometries are particularly susceptible to these variations since the cooling rates in the various regions of the casting are geometry dependant. For example, in a region having a high ratio of local surface area to volume, the faster the region will tend to cool. In a region having a low ratio of local surface area to volume, the slower the region will tend to cool. This results in material properties which vary significantly from one region to another region within the casting.

[0003] Such variations in material properties within a casting are often undesirable. The variations can cause problems with machinability or other processing. Issues with product performance can also arise.

[0004] It would be desirable to develop a casting method and mold design for optimization of material properties of a casting.

SUMMARY OF THE INVENTION

[0005] Concordant and congruous with the present invention, a casting method and mold design for optimization of material properties of a casting, has surprisingly been discovered.

[0006] In one embodiment, the casting apparatus comprises a first mold pattern for forming a first mold cavity for receiving a molten material therein; and a second mold pattern positioned adjacent at least a portion of said first mold pattern, said second mold pattern forming a second mold cavity for receiving the molten material therein, wherein the molten material in the second mold cavity controls a cooling rate of the molten material in the portion of the first mold cavity.

[0007] In another embodiment, a mold for casting comprises a mold having a first mold cavity and a second mold cavity formed therein and adapted to receive a molten material, the second mold cavity formed adjacent at least a portion of the first mold cavity, wherein the molten material received in the second mold cavity controls a cooling rate of the molten material received in the portion of the first mold cavity adjacent the second mold cavity.

[0008] The invention also provides a method of controlling the cooling rate of molten material in a casting process that comprises the steps of providing a first mold pattern for forming a first mold cavity for receiving a molten material; providing a second mold pattern for forming a second mold cavity for receiving a molten material; positioning the second mold pattern adjacent at least a portion of the first mold pattern; and introducing molten material into the first mold cavity and the second mold cavity, wherein the molten material in the second mold cavity controls the cooling rate of the molten material in the portion of the first mold cavity.

[0009] The apparatus and method of this invention are useful in a casting process. The apparatus and method are particularly useful in the casting of engine components such as engine blocks, cylinder heads, and complex transmission components, for example.

DESCRIPTION OF THE DRAWINGS

[0010] The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description of a preferred embodiment when considered in the light of the accompanying drawings in which:

[0011] Fig. 1 is a top plan view of a casting apparatus known in the art;

[0012] Fig. 2 is a graphical representation of temperature versus time data taken at three points along a crankshaft produced using the prior art casting apparatus of Fig. 1;

[0013] Fig. 3 is a top plan view of a crankshaft made with the prior art casting apparatus of Fig. 1 and showing variations in Brinell hardness along a length of the crankshaft;

[0014] Fig. 4 is a top plan view of an casting apparatus according to an embodiment of the invention;

[0015] Fig. 5 is a perspective view of the casting apparatus of Fig. 4;

[0016] Fig. 6 is a graphical representation of temperature versus time taken at three points along a crankshaft produced using the casting apparatus of Fig. 4;

[0017] Fig. 7 is a top plan view of a crankshaft made with the casting apparatus of Fig. 4 and showing the Brinell hardness along the length of the crankshaft; and

[0018] Fig. 8 is a block diagram illustrating a method according to one embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0019] The following detailed description and appended drawings describe and illustrate various exemplary embodiments of the invention. The description and drawings serve to enable one skilled in the art to make and use the invention, and are not intended to limit the scope of the invention in any manner. In respect of the methods disclosed, the steps presented are exemplary in nature, and thus, the order of the steps is not necessary or critical.

[0020] Fig. 1 shows a casting apparatus 10 according to the prior art. The casting apparatus 10 is a casting pattern for a mold (not shown) as used in known casting processes such as investment casting, sand casting, permanent mold casting, and die casting, for example. The casting apparatus 10 includes a pair of mold patterns 12, a gate 14, and risers 16.

[0021] The mold patterns 12 include a flange 18, a body portion 20, and a stem 22. The mold patterns 12 have a shape substantially similar to a desired cast object. Fig. 1 shows the mold patterns 12 with a shape substantially similar to a crankshaft 24 as shown in Fig. 3. It is understood that the mold patterns 12 may have the shape of any desired cast object, such as engine blocks, cylinder heads, complex transmission components, and the like, for example.

[0022] The gate 14 forms a conduit (not shown) in the mold that includes an inlet 26 to provide fluid communication with the mold patterns 12 and the risers 16. Fig. 1 shows the gate 14 located near the bottom of the casting apparatus 10. It is understood that the gate 14 may be any size or shape and the gate 14 may be located in other areas of the casting apparatus 10, as desired.

[0023] The risers 16 are adapted to form reservoirs (not shown) that militate against the formation of cavities or voids in the desired cast object due to shrinkage of a molten material (not shown) during a cooling thereof. Fig. 1 shows a pair of the risers 16 with one of the risers 16 associated with each of the mold patterns 12. It is understood that any shape, size, location, and number of risers may be used, so long as an adequate amount of molten material is provided in the risers 16 to militate against the formation of cavities or voids in the cast object. It is further understood that the molten material may be any metal or non-metal, as desired.

[0024] In use, the casting apparatus 10, including the cavities formed by the mold patterns 12, is filled with the molten material through the conduit formed by the inlet 26 of the gate 14. In sand casting, for example, the cavities and the conduit are formed in a sand mold. The molten material flows through the casting apparatus 10, filling the mold patterns 12 and the risers 16.

[0025] Once the mold cavity formed by the patterns 12 has been filled, the molten material is allowed to cool. Because metals are less dense in the liquid state than in the solid state, the volume occupied by the desired cast object will decrease as it cools. Thus, formation of cavities or voids is possible, generally at the last point to solidify. The risers 16 militate against the formation of cavities or voids in the desired cast object by providing additional molten material to the mold patterns 12. Therefore, as the molten material solidifies and shrinks, any cavities or voids that form do so in the risers 16 and not in the desired cast object. Once the desired cast object has solidified and sufficiently cooled, the mold is opened or removed from the cast object. Hardened material from the cavities formed by the gate 14 and the risers 16 is attached to the desired cast object. The hardened material from the gate 14 and the risers 16 is removed from the desired cast object using methods known in the art, and then discarded or recycled.

[0026] Fig. 2 shows a graph 27 of temperature versus time data for a casting produced from the casting apparatus of Fig. 1. The graph 27 includes a temperature axis 28 (the y-axis), a time axis 30 (the x-axis), a flange line 32, a body portion line 34, a stem line 36, a shakeout line 38, and a eutectoid line 40.

[0027] The flange line 32, the body portion line 34, and the stem line 36 represent a plot of temperature versus time measurements as measured by thermocouples (not shown) located at the flange 18, the body portion 20, and the stem 22, respectively. The thermocouples measure the temperature of the molten material during solidification, cooling, and shakeout periods.

[0028] The shakeout line 38 graphically represents the time period when the crankshaft 24 is removed from the mold. The shakeout line 38 is shown at a time between one hundred (100) minutes and one hundred ten (110) minutes. It is understood that that shakeout line 38 can represent any desired time period based on the size or shape of the desired cast object, the temperature range of the material used to make the desired cast object, or other similar factors.

[0029] The eutectoid line 40 graphically represents the temperature at which eutectoid transformation occurs. Eutectoid transformation occurs in a reaction wherein, upon cooling, one solid phase transforms isothermally and reversibly into two new solid phases that are intimately mixed. Fig. 2 shows the eutectoid line 40 at a temperature of approximately 700 degrees Celsius. It is understood that the temperature at which eutectoid transformation occurs will vary based on the properties of the materials used to cast the desired cast object. Accordingly, the eutectoid line 40 may be at other temperatures, depending upon the material used. It is understood that some alloys, such as aluminum for example, do not go through a eutectoid transformation; however, a rate of solidification or rate of freezing may be controlled to affect the alloy's strength by altering a grain size, a dendrite arm spacing, or other similar characteristic of the alloy, as desired.

[0030] The flange line 32, the body portion line 34, and the stem line 36 cross the shakeout line 38 at the same time, and the different parts of the crankshaft 24 represented continue to cool at different rates. The flange line 32, the body portion line 34, and the stem line 36 cross the eutectoid line 40 at different times. The flange line 32 crosses the eutectoid line 40 at a time between one hundred (100) minutes and one hundred ten (110) minutes, which is after the shakeout period. The body portion line 34 crosses the eutectoid line 40 at a time between sixty (60) minutes and seventy (70) minutes, which is before the shakeout period. The stem line 36 crosses the eutectoid line 40 at a time between forty (40) minutes and fifty (50) minutes, which is also before the shakeout period. It is understood that that the flange line 32, the body portion line 34, and the stem line 36 may cross the eutectoid line 40 at any time based on the size or shape of the desired cast object, the temperature range or properties of the material used to make the desired cast object, the casting process used, or other similar factors. Because the flange line 32, the body portion line 34, and the stem line 36 illustrate different cooling rates for different parts of the crankshaft 24 the material properties from one part of the crankshaft 24 to another vary.

[0031] Fig. 3 shows a hardness distribution of the crankshaft 24 formed using the casting apparatus 10 known in the art. The Brinell hardness scale was used to show the non-uniform hardness distribution of the crankshaft 24. The Brinell hardness scale characterizes the indentation hardness of materials through the scale of penetration of an indenter. The typical test uses a 10 mm diameter steel ball as the indenter with a 3,000 kgf (29 kN) force. For softer materials, a smaller force is used; for harder materials, a tungsten carbide ball is substituted for the steel ball. The hardness is calculated using the following equation: Brinell Harness Number (BHN) = $P/[\Pi^*D^*(D-\sqrt{(D^2-d^2)})]$, where P is the force applied, D is the diameter of the indenter, and d is the diameter of the indentation. It is understood that there are a number of other hardness tests that may be used to determine the hardness distribution of the desired cast object.

[0032] The crankshaft 24 includes a stem portion 42, a lower body portion 44, an upper body portion 46, and a flange portion 48. The stem portion 42 and the lower body portion 44 have BHNs between 141.0 and 220.03. The upper body portion 46 and flange portion 48 have BHNs between 273.0 and 326.0. The difference in hardness, represented by BHNs, is an effect of the stem portion 42 and the lower body portion 44 cooling at different rates than the upper body portion 46 and flange portion 48. As described above, the difference in cooling rates from one region of a desired cast object to another region results in different rates of eutectoid transformation. Different rates of eutectoid transformation results in the desired cast object having different material properties from one region thereof to another.

[0033] Figs. 4 and 5 show a casting apparatus 60 according to an embodiment of the invention. The casting apparatus 60 is a casting pattern for a mold (not shown) that may be used in any known casting process such as investment casting, sand casting, permanent mold casting, and die casting, for example. The casting apparatus 60 includes a pair of first mold patterns 62, a second mold pattern 64, a gate 66, and risers 68. It is understood that more or fewer mold patterns 62, 64 can be used as desired.

[0034] The first mold patterns 62 include a flange 70, a body portion 72, and a stem 74. The first mold patterns 62 are adapted to form a mold cavity (not shown) in the mold which is in fluid communication with a mold cavity (not shown) formed by the gate 66, and the risers 68. The first mold patterns 62 have a shape substantially similar to a desired cast object. In the embodiment shown, the first mold patterns 62 have a shape substantially similar to a crankshaft 76, as shown in Fig. 7. It is understood that the first mold patterns 62 may have the shape of any desired cast object such as engine blocks, cylinder heads, complex transmission components, and the like, for example.

[0035] In the embodiment shown, the second mold pattern 64 includes an inner wall 78 and an outer wall 80. The second mold pattern 64 is adapted to form a mold cavity (not shown) which is in fluid communication with a conduit (not shown) which is part of the cavity formed by the gate 66, and the risers 68. The inner wall 78 and the outer wall 80 of the second mold pattern 64 are configured to circumscribe the two-dimensional shape of the profile of the stem 74 of the first mold patterns 62. The term circumscribe as used herein means that the inner wall 78 and the outer wall 80 of the second mold pattern 64 at least partially surround, in close proximity to but without actually contacting, the first mold pattern 62. It is understood that the inner wall 78 of the second mold pattern 64 may be any shape or configuration desired such as the shape of a particular portion of the first mold patterns 62, or any geometric shape, for example. It is also understood that the inner wall could circumscribe a particular portion of the first mold pattern 62 three-dimensionally. The outer wall 80 may be any shape or configuration, as desired. The second mold pattern 64 may also have a shape substantially similar to another desired cast object. It is further understood that the second mold pattern 64 may be positioned at any distance from the first mold pattern 62, as desired. The exact configuration and position of the second mold pattern 64 will depend on the size, shape, and surface area of the first mold patterns 62, the desired cooling rate of molten material filling the cavity formed by the first mold patterns 62, and the like, for example. As shown, the second mold pattern 64 is positioned adjacent the stem 74 of the first mold patterns 62. It is understood that the second mold pattern 64 may be positioned adjacent any portion of the first mold patterns 62 such as the flange 70, the body portion 72, or any combination of the portions of the first mold patterns 62, as desired.

[0036] The gate 66 forms the conduit that includes an inlet 82 to provide fluid communication with the first mold patterns 62, the second mold pattern 64, and the risers 68. In the embodiment shown, the gate 66 is located near the bottom of the casting apparatus 60. It is understood that the gate 66 may be any gate known in the art. The gate 66 may be any size or shape and the gate 66 may be located anywhere on the casting apparatus 60, as desired.

[0037] The risers 68 are adapted to form reservoirs (not shown) that militate against the formation of cavities or voids in the desired cast object due to shrinkage of a molten material (not shown) during a cooling thereof. Figs. 4 and 5 show a pair of risers 68 with one of the risers 68 associated with each of the first mold patterns 62. It is understood that any shape, size, location, and number of the risers 68 may be used so long as an adequate amount of molten material is provided in the risers 68 to militate against the formation of cavities and voids in the desired cast object. It is further understood that the molten material may be any metal or non-metal, as desired.

[0038] In use, the casting apparatus 60, including the cavities formed by the first mold patterns 62 and the second mold pattern 64, are filled with the molten material through the conduit formed by the inlet 82 of the gate 66. The molten material flows through the casting apparatus 60 filling the mold cavities formed by the first mold patterns 62, the second mold pattern 64, and the risers 68.

[0039] Once the mold cavities have been filled, the casting apparatus 60 and the desired cast object are allowed to cool. Because metals are less dense in the liquid state than in the solid state, the volume occupied by the desired cast object will decrease as it cools. Thus, formation of cavities or voids is possible, generally at the last point to solidify. The risers 68 militate against the formation of cavities or voids in the desired cast object by providing additional molten material to the cavity formed by the first mold patterns 62. Therefore, as the molten material solidifies and shrinks any cavities or voids that form, do so in the risers 68 and not in the desired cast object. A cooling rate of the portion of the cast object adjacent the mold cavity formed by the second mold pattern 64 is controlled by the heat radiating from the molten material in the mold cavity formed by the second mold pattern 64. If the portion of the cast object formed in the cavity formed by the first mold patterns 62 adjacent to the cavity formed by the second mold pattern 64 would normally cool faster than the other portions of the cast object, the cooling rate of the cast object formed in the cavity formed by the first mold patterns 62 is decreased by the radiating heat. It is understood that a plurality of mold patterns may be used to control the cooling rate of the first mold pattern 64 without departing from the scope of the invention.

[0040] Once the desired cast object has solidified and sufficiently cooled the mold is opened and the desired cast object is removed. Hardened material from the cavities or conduits formed by the gate 66, the risers 68, and the second mold pattern 64 is attached to the desired cast object. The hardened material is removed from the desired cast object using methods known in the art, and then discarded or recycled.

[0041] Fig. 6 shows a graph 83 of temperature versus time data for a casting produced from the casting apparatus 60. The graph 83 includes a temperature axis 84 (the y-axis), a time axis 86 (the x-axis), a flange line 88, a body portion line 90, a stem line 92, a shakeout line 94, and a eutectoid line 96.

[0042] The flange line 88, the body portion line 90, and the stem line 92 represent a plot of temperature versus time measurements as measured by thermocouples (not shown) located at the flange 70, the body portion 72, and the stem 74, respectively. The thermocouples measure the temperature of the molten material during solidification, cooling, and shakeout periods.

[0043] The shakeout line 94 graphically represents the time period when the crankshaft 76 is removed from the mold. For purposes of illustration, the shakeout line 94 is shown at a time between one hundred (100) minutes and one hundred ten (110) minutes. It is understood that that shakeout line 94 may represent any desired time period based on the size or shape of the desired cast object, the temperature range of the material used to make the desired cast object, or other similar factors.

[0044] The eutectoid line 96 graphically represents the temperature at which eutectoid transformation occurs. Eutectoid transformation occurs in a reaction wherein, upon cooling, one solid phase transforms isothermally and reversibly into two new solid phases that are intimately mixed. Fig. 6 shows the eutectoid line 96 at a temperature of approximately 700 degrees Celsius. It is understood that the temperature at which eutectoid transformation occurs will vary based on the properties of the materials used to cast the desired cast object. Accordingly, the eutectoid line 96 may be at other temperatures depending upon the material used. It is understood that some alloys, such as aluminum for example, do not go through a eutectoid transformation; however, a rate of solidification or rate of freezing may be controlled to affect the alloy's strength by altering a grain size, a dendrite arm spacing, or other similar characteristic of the alloy, as desired.

[0045] The flange line 88, the body portion line 90, and the stem line 92 have substantially similar cooling rates and cross the shakeout line 94 at substantially the same time. Because the flange line 88, the body portion line 90, and the stem line 92 have substantially similar cooling rates, the flange line 88, the body portion line 90, and the stem line 92 cross the eutectoid line 96 at the substantially same rate and time. In the embodiment shown, the flange line 88, the body portion line 90, and the stem line 92 all cross the eutectoid line 96 at the same rate, at a time between one hundred five (105) minutes and one hundred ten (115) minutes, which is after the shakeout period. As a result of the substantially similar cooling rates and the substantially similar rates of eutectoid transformation, the material properties from one portion to another within the casting will be substantially the same. It is understood that that the flange line 88, the body portion line 90, and the stem line 92 may cross the eutectoid line 96 at other times based on the size or shape of the desired cast object, the temperature or properties of the molten material used to make the desired cast object, the casting process used, or other similar factors.

[0046] Fig. 7 shows a hardness distribution of the crankshaft 76 formed using the casting apparatus 60. The Brinell hardness scale was used to show the non-uniform hardness distribution of the crankshaft 76. It is understood that there are a number of other hardness tests that may be used to determine the hardness distribution of the desired cast object.

[0047] The crankshaft 76 shown includes a stem portion 98, a lower body portion 100, an upper body portion 102, and a flange portion 104. In the embodiment shown, the stem portion 98, the lower body portion 100, the upper body portion 102, and the flange portion 104 all have BHNs between 273.0 and 326.0. This data is used for illustrative purposes to show the consistent material properties and is not intended to limit the scope of the invention. The substantially uniform hardness is a result of the stem portion 98, the lower body portion 100, the upper body portion 102, and the flange portion 104 cooling at the substantially same rate. As described above, the substantial similarity of the cooling rates from one region of the desired cast object to another results in similar times of eutectoid transformation. Similar rates of eutectoid transformation cause the desired cast object to have substantially similar material properties from one portion of the desired cast object to another.

[0048] Fig. 8 schematically illustrates a method 110 of controlling the cooling rate of molten material in a first mold cavity according to one embodiment of the invention. The method 110 may be used with any known casting process, such as investment casting, sand casting, permanent mold casting, and die casting, for example.

[0049] In a first step 112, a first mold cavity is formed which is adapted to receive a molten material. The first mold cavity may be any size or shape as desired to produce a desired cast object. The first mold cavity may be the size or shape of a crankshaft, an engine block, a cylinder head, a complex transmission component, and the like, for example.

[0050] In a second step 114, a second mold cavity is formed which is adapted to receive a molten material. The second mold cavity may be configured to circumscribe the two-dimensional profile of a portion of the first mold cavity. It is understood that second mold cavity may be any shape or configuration desired such as the shape of a particular portion of the first mold cavity, or any geometric shape, for example. It is also understood that the second mold cavity could circumscribe a particular portion of the first mold cavity three-dimensionally. The second mold cavity may be any shape or configuration, as desired. The second mold cavity may also have a shape substantially similar to another desired cast object. It is further understood that the second mold cavity may be positioned at any distance from the first mold cavity, as desired. The exact configuration and position of the second mold cavity will depend on the size, shape, and surface area of the first mold cavity, as well as the desired cooling rate of the molten material in the first mold cavity.

[0051] In a third step 116, the second mold cavity is positioned adjacent a portion of the first mold cavity. It is understood that the second mold cavity may be placed adjacent one side, two sides, or completely surrounding the portion of the first mold cavity.

[0052] In a fourth step 118, a molten material is introduced into the first mold cavity and the second mold cavity, wherein the heat radiating from the second mold cavity controls the cooling rate of the molten material inside the portion of the first mold cavity. The cooling rate of the portion of the molten material in the first mold cavity adjacent to the second mold cavity may be controlled so that the portion adjacent to the second mold cavity cools at a substantially similar rate as the remaining portions of the molten material in the first mold cavity. Alternatively, the cooling rate of the portion of the molten material in the first mold cavity adjacent to the second mold cavity may be controlled so that the portion adjacent to the second mold cavity cools at a slower rate than the rest of the molten material in the first mold cavity.

[0053] From the foregoing description, one ordinarily skilled in the art can easily ascertain the essential characteristics of this invention and, without departing from the spirit and scope thereof, can make various changes and modifications to the invention to adapt it to various usages and conditions.

Claims

1. A casting apparatus (60) comprising:

> a first mold pattern (62) for forming a first mold cavity for receiving a molten material therein, and
>
> a second mold pattern (64) positioned adjacent at least a portion of said first mold pattern (62), said second mold pattern (64) forming a second mold cavity for receiving the molten material therein, wherein the molten material in the second mold cavity controls a cooling rate of the molten material in the portion of the first mold cavity.

2. The apparatus of Claim 1, wherein said first mold pattern (62) and said second mold pattern (64) are patterns for a sand casting process.

3. The apparatus (60) of Claim 1, wherein said first mold pattern (62) and said second mold pattern (64) are patterns for a die casting process.

4. The apparatus (60) of Claim 1, wherein said first mold pattern (62) and said second mold pattern (64) are patterns for an investment casting process.

5. The apparatus (60) of Claim 1, wherein said first mold pattern (62) and said second mold pattern (64) are patterns for a permanent mold casting process.

6. The apparatus (60) of Claim 1, wherein said second mold pattern (64) is adjacent at least one side of said first mold pattern (62).

7. The apparatus (60) of Claim 6, wherein said second mold pattern (64) is adjacent two sides of said first mold pattern (62).

8. The apparatus (60) of Claim 6, wherein said second mold pattern (64) is adjacent three sides of said first mold pattern (62).

9. The apparatus (60) of Claim 1, wherein said second mold pattern (64) surrounds at least a portion of said first mold pattern (62).

10. A mold (60) for casting comprising:

a mold (62, 64) having a first mold cavity and a second mold cavity formed therein and adapted to receive a molten material, the second mold cavity formed adjacent at least a portion of the first mold cavity,

wherein the molten material received in the second mold cavity controls a cooling rate of the molten material received in the portion of the first mold cavity adjacent the second mold cavity.

11. The mold (60) of Claim 10, wherein said mold (62, 64) is a sand casting mold.

12. The mold (60) of Claim 10, wherein said mold (62, 64) is a die casting mold.

13. The mold (60) of Claim 10, wherein said mold (62, 64) is an investment casting mold.

14. The mold (60) of Claim 10, wherein said mold (62, 64) is a permanent mold casting mold.

15. The mold (60) of Claim 10, wherein the second mold cavity is adjacent one side of the first mold cavity.

16. The mold (60) of Claim 15, wherein the second mold cavity is adjacent two sides of the first mold cavity.

17. The mold (60) of Claim 15, wherein the second mold cavity is adjacent three sides of the first mold cavity.

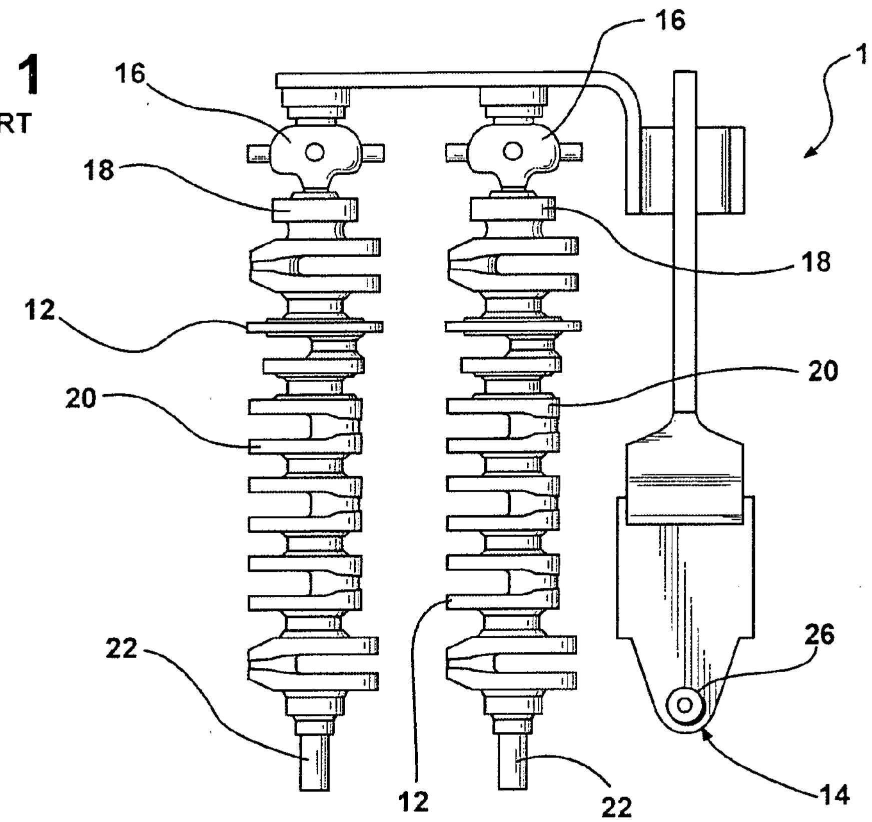
18. The mold (60) of Claim 10, wherein the second mold cavity surrounds at least a portion of the first mold cavity.

19. A method (110) of controlling the cooling rate of molten material
in a casting process comprising the steps of:

providing a first mold pattern (62) for forming a first mold cavity for receiving a molten material (112);
providing a second mold pattern (64) for forming a second mold cavity for receiving a molten material (114);
positioning the second mold pattern (64) adjacent at least a portion of the first mold pattern (62), (116); and
introducing molten material into the first mold cavity and the second mold cavity, wherein the molten material in the second mold cavity controls the cooling rate of the molten material in the portion of the first mold cavity (118).

20. The method (110) of Claim 19, wherein the second mold pattern (64) is positioned adjacent at least one side of the first mold pattern (62).

FIG - 1
PRIOR ART



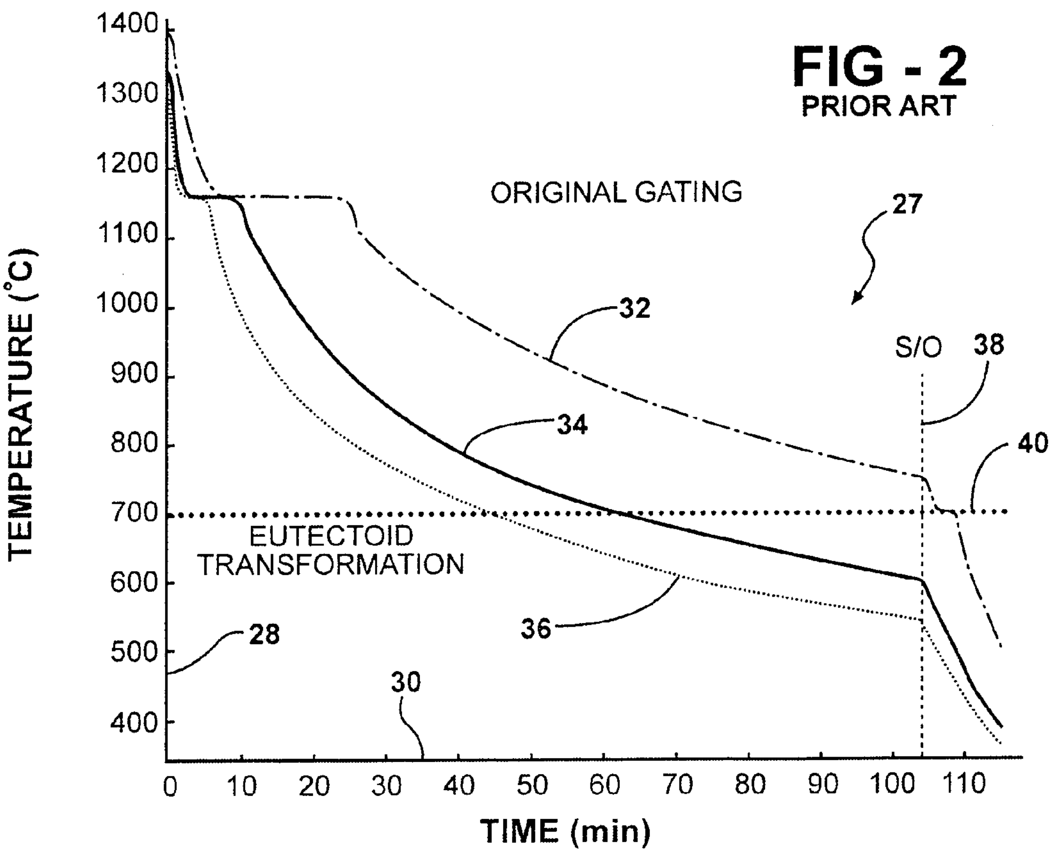


FIG - 2
PRIOR ART

FIG - 3
PRIOR ART

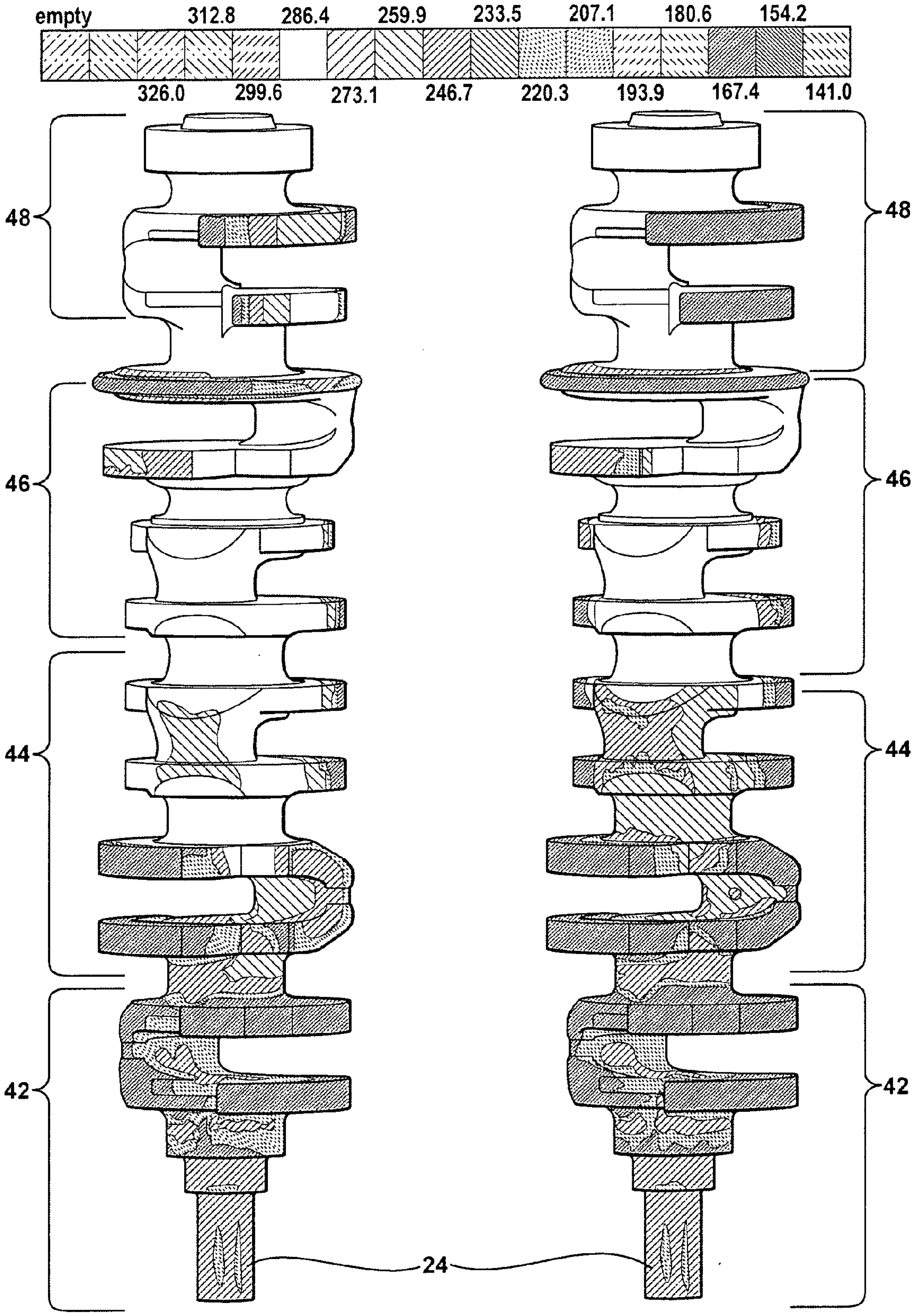
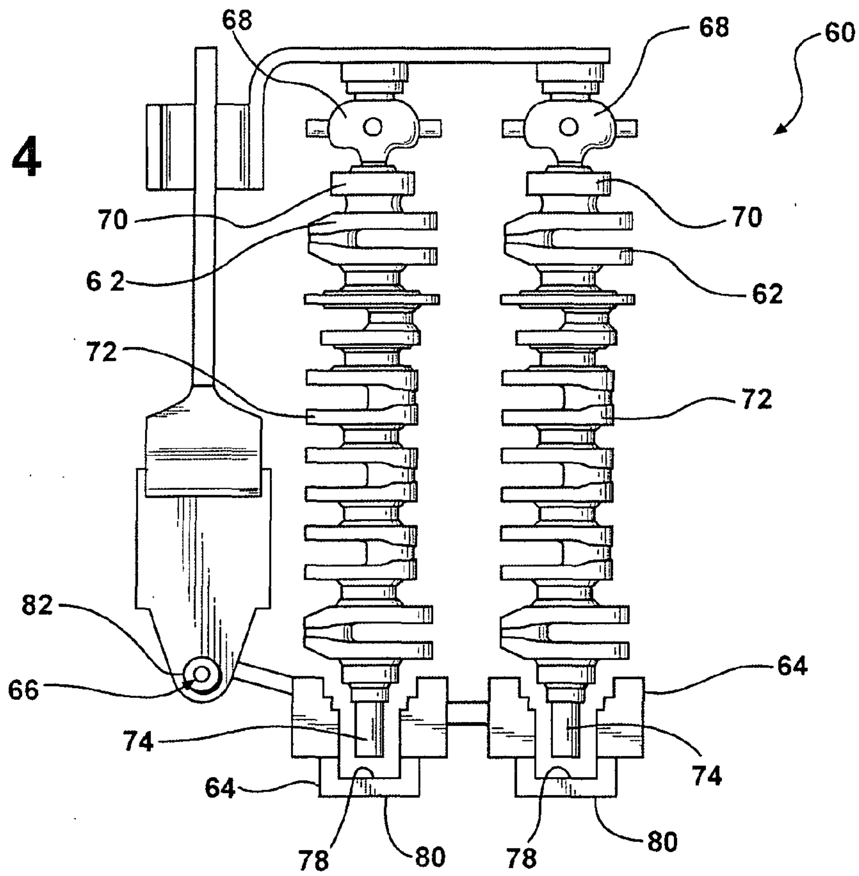


FIG - 4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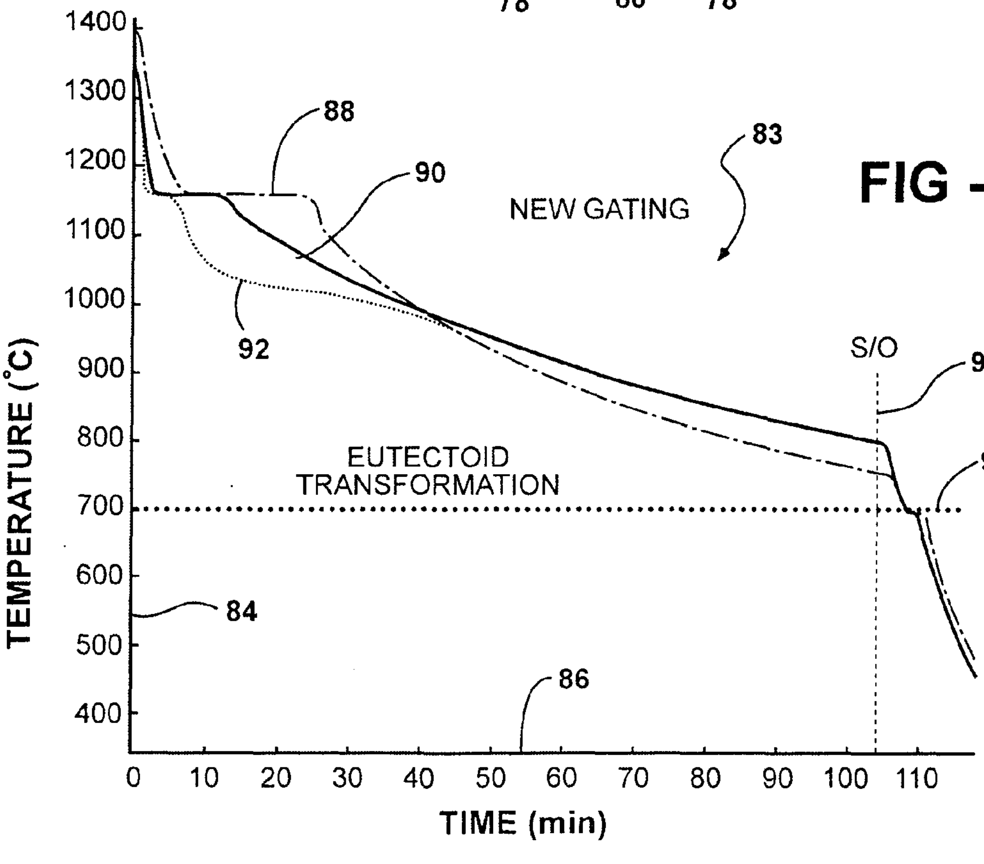
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S/O
94
96
EUTECTOID
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TIME (min)

FIG - 6

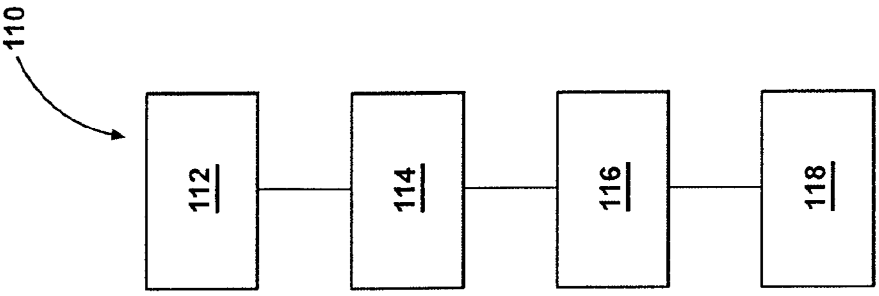


FIG - 8

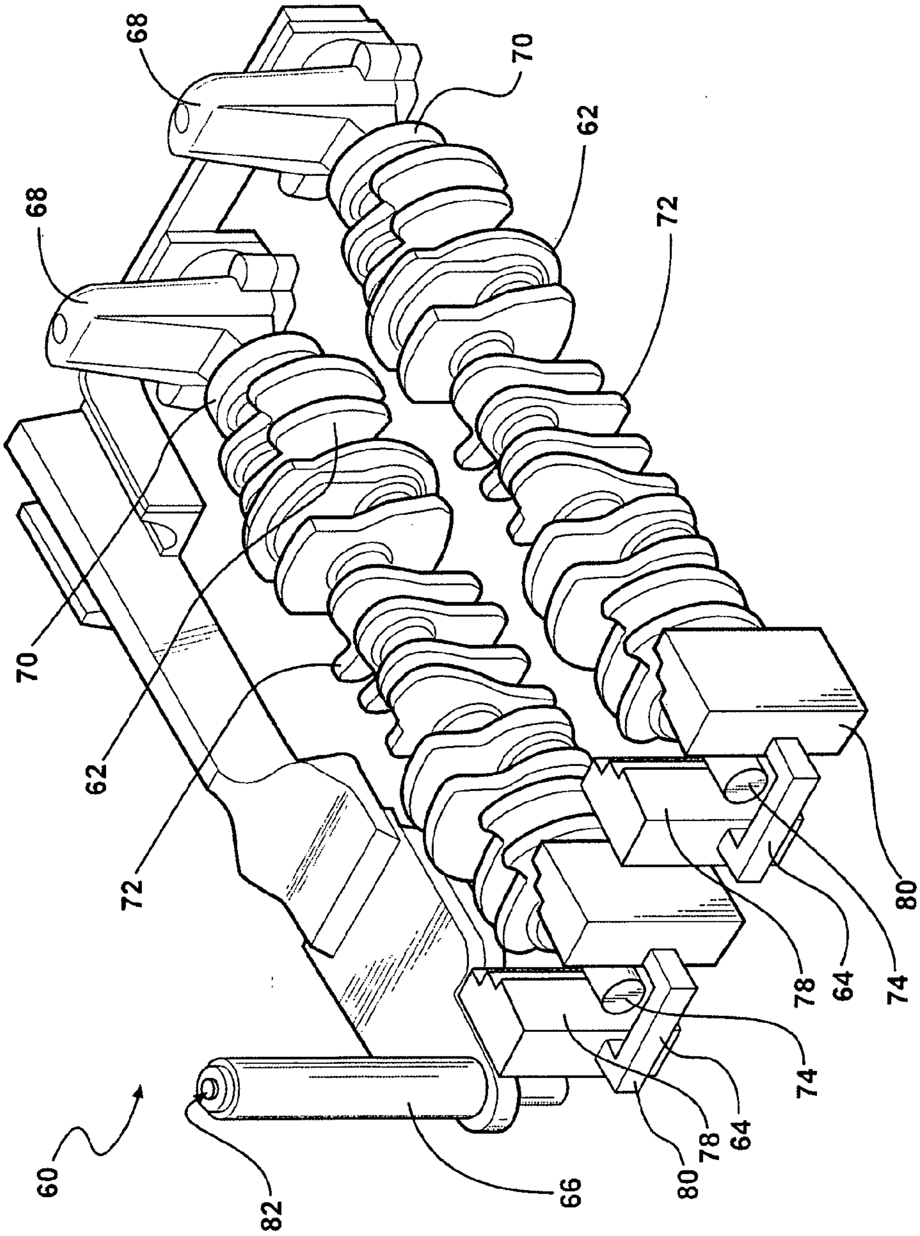
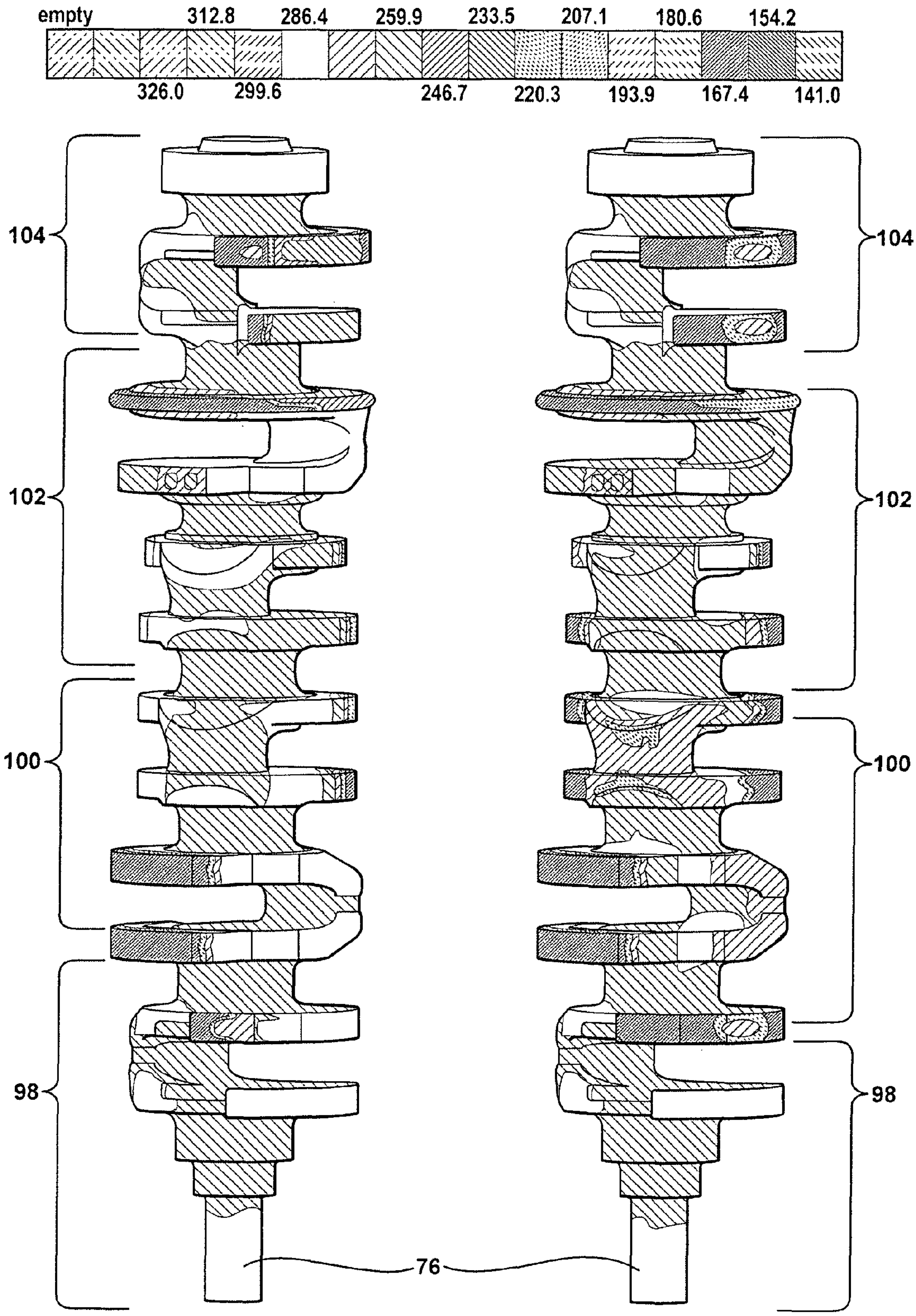


FIG - 5

FIG - 7


empty
312.8
286.4
259.9
233.5
207.1
180.6
154.2
326.0
299.6
246.7
220.3
193.9
167.4
141.0
104
102
100
98
76