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(54) **Method and apparatus for pulsed pressure molding**

(57) Method and apparatus for creating a molded product by first liquefying a metal in a crucible disposed in a crucible chamber and then applying a differential pressure level to the liquefied metal so as to force the liquefied metal into a mold. Once the liquefied metal is drawn into the mold, the pressure of the liquefied metal in the mold is raised to a solidification pressure in oscillating pressure steps. Once the pressure is raised to the solidification pressure, the liquefied metal is allowed to solidify.

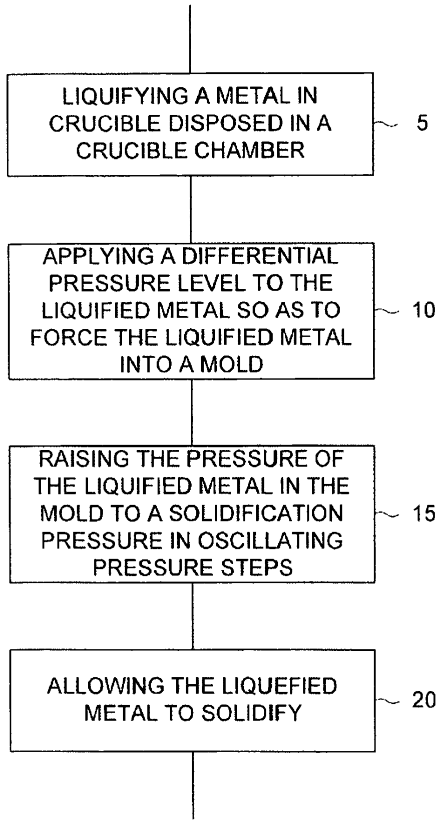

FIG. 1

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Description

RELATED APPLICATIONS

[0001] The present application claims priority to United States Provisional Application Serial Number 60/762,069, entitled "Method and Apparatus for Pulsed Pressure Molding" by Stoyanov et al, and which was filed on January 24, 2006.

BACKGROUND

[0002] Up until now, molding techniques have not really evolved since the days where molten metal was forced into a preformed cavity in order to manufacture a useful metal component. During the crude evolution of molding technology, the techniques were improved upon namely in the means by which molten metal was forced into the preformed cavity, which is typically referred to as a "mold".

[0003] In early days, molten metal was simply poured into the mold and then allowed to cool. The cast component was then freed from the mold and, in some cases, subject to additional processing. Additional evolution in molding technology recognized that simply filling a cavity using nothing more than gravity was not as effective as forcing the molten metal into the cavity under pressure. Pressure molding machines applied pressure to the molten metal in order to direct the molten metal into a cavity, thus ensuring that every portion of the cavity could be uniformly filled with the molten metal.

[0004] Different types of pressure could be applied in order to fill a cavity. For example, positive pressure could be used to drive molten metal from a crucible into the mold. Negative pressure could be applied around the mold, which results in drawing the molten metal into the cavity. A combination of positive and negative pressure has also been utilized in order to more effectively fill the cavity with molten metal.

[0005] The use of pressure to fill the mold cavity also had some additional benefits. By using pressure, the density of the molten metal could be improved. By increasing the density of the molten metal, a superior cast component could be produced since the molecules in the final molded component were more closely related to each other. But this effect was only a marginal improvement and was proportional to the amount of pressure applied to the molten metal. There is a practical limit to the amount of pressure that could be applied to the molten metal, so there is no way of improving the marginal improvement in molecular density realized by the application of pressure to the molten metal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Several alternative embodiments will hereinafter be described in conjunction with the appended drawings and figures, wherein like numerals denote like elements, and in which:

Fig. 1 is a flow diagram that depicts one example method for pulsed pressure molding;

Fig. 2 is a flow diagram that depicts an alternative method for applying a differential pressure to a liquefied metal;

Fig. 3 is a flow diagram that depicts yet another alternative method for applying a differential pressure to a liquefied metal;

Fig. 4 is a flow diagram that depicts an alternative example method for raising the pressure of the liquefied metal in oscillating pressure steps;

Fig. 5 is a flow diagram that depicts alternative example methods for applying a gaseous pressure to the liquefied metal;

Figs. 6 and 7 collectively form a flow diagram that depicts an alternative method for raising the pressure applied to liquefied metal in the mold using a mechanical means;

Fig. 7A is a pictorial illustration of one example pressure profile useful in pulsed-pressure counter pressure molding;

Fig. 8 is a pictorial illustration of an alternative example pressure profile useful in vacuum pressure molding;

Figs. 9 through 12 are pictorial illustrations that depict alternative example pressure profiles useful in other molding methods;

Fig. 13 is a pictorial diagram that illustrates the structure of one example embodiment of a molding machine; and

Fig. 14 is a pictorial illustration of an alternative example embodiment of a molding machine that includes the gate valve for isolating liquefied metal in the mold from the crucible.

DETAILED DESCRIPTION

[0007]

Fig. 1 is a flow diagram that depicts one example method for pulsed pressure molding. According to this example method, a casting is formed by liquefying a metal in a crucible wherein the crucible is disposed in a crucible chamber (step 5). A differential pressure is applied to the liquefied metal so as to force the liquefied metal into a mold (step 10). Once the liquefied metal is in the mold, the pressure applied to liquefied metal is raised in order to reach a solidification pressure. It should be appreciated that according to this example method, the pressure is increased in oscillating and increasing pressure steps (step 15). Once the solidification pressure is reached, the liquefied metal is allowed to solidify (step 20). It should be appreciated that, according to this example method, increasing the pressure upon the liquefied metal in oscillating and increasing pressure steps results in pressure impulses, as post compression, in the mold cavity. This post compression breaks crystal buildup in the metal and increases the density and solidification properties of the liquefied metal forced into the mold by the application of differential pressure. Accordingly, the shrink porosity in a resulting casting is thus substantially reduced or, in some cases virtually eliminated.

Fig. 2 is a flow diagram that depicts an alternative method for applying a differential pressure to a liquefied metal. According to this variation of the present method, a differential pressure is applied to liquefied metal by increasing the pressure in a crucial chamber (step 25).

Fig. 3 is a flow diagram that depicts yet another alternative method for applying a differential pressure to a liquefied metal. According to this variation of the present method, a differential pressure is applied to the liquefied metal by decreasing the pressure in a mold chamber (step 30).

Fig. 4 is a flow diagram that depicts an alternative example method for raising the pressure of the liquefied metal in oscillating pressure steps. According to this example method, the pressure of the liquefied metal is increased by applying a gaseous pressure at a first level to the liquefied metal in the mold. It should be appreciated that this first pressure level is greater than the differential pressure originally applied to the liquefied metal (step 35). The gaseous pressure is then reduced to a level where the reduced level is still greater than the originally applied differential pressure (step 40). The gaseous pressure is then increased to a second level that is greater than the first gaseous pressure level (step 45).

Fig. 5 is a flow diagram that depicts alternative example methods for applying a gaseous pressure to the liquefied metal. According to one alternative example method, gaseous pressure is applied to the mold chamber (step 50). According to another alternative method, gaseous pressure is applied to crucible chamber (step 55).

Figs. 6 and 7 collectively form a flow diagram that depicts an alternative method for raising the pressure applied to liquefied metal in the mold using a mechanical means. According to this variation of the present method, raising the pressure of the liquefied metal in the mold is accomplished by isolating the liquefied metal in the crucible from the liquefied metal in the mold (step 55). Once the liquefied metal in the mold is isolated from the liquefied metal in the crucible, mechanical pressure at a first level is applied to the liquefied metal in the mold. It should be appreciated that this first level of mechanical pressure is greater than the originally applied differential pressure used to force the liquefied metal into the mold (step 60). The mechanical pressure is then reduced to a lower level, wherein the reduced level is still greater than the originally applied differential pressure (step 65). The mechanical pressure is then increased to a second level, which is greater than the first mechanical pressure level applied to the liquefied metal (step 70).

Fig. 7A is a pictorial illustration of one example pressure profile useful in pulsed-pressure counter pressure molding. According to one illustrative method, counter pressure molding is accomplished by raising the pressure in a crucible chamber and in a mold chamber to a initial pressure (P0) 75. At this point, the pressure in the mold chamber is maintained for a period of time 80 until the liquefied metal flows into a mold. During the same period of time, additional pressure is applied to the crucial chamber until the mold is filled (Pf) with liquefied metal, which occurs at 85 in the profile. The pressure applied to the liquefied metal in the mold is then reduced to a first reduced pressure level 90, which is greater than the initial pressure P0 at 80. The pressure applied to the liquefied metal is then increased to a level 95 this greater than the flow pressure Pf 85. It should be appreciated that the time to reduce the pressure from level 85 down to level 90 is somewhat longer than the time expended in increasing the pressure from level 90 through 95. This shortened rise time results in a pulsing action upon the liquefied metal. It should be appreciated that additional cycles of reducing and increasing the pressure upon the liquefied metal are applied according to an alternative variation of the present method until a solidification pressure is achieved 100. It should be appreciated that the pulsing of pressure is typically, but not necessarily applied in a manner where pressure is increased at a rate that is faster (i.e. delta pressure over delta time) than it is decreased. Again, this results in a pressure impulse that causes breakdown of metal crystallization as described heretofore. The change in pressure over time is referred to as the slope of the pressure profile.

Fig. 8 is a pictorial illustration of an alternative example pressure profile useful in vacuum pressure molding. In this example method, a negative pressure, or a vacuum, is applied to a mold chamber, thereby drawing the liquefied metal into a mold situated in the mold chamber. The liquefied metal, once drawn into the mold, is found at a vacuum pressure level 105. In this example method, the negative pressure is maintained for some period of time allowing the liquefied metal to settle in the mold. The pressure applied to the liquefied metal is then increased to a first positive pressure level 110. This additional pressure is typically applied as additional positive pressure to the crucible, from whence the liquefied metal is drawn into the mold. The increase in pressure to the first positive pressure level 110 must be accomplished rapidly in order to prevent the liquefied metal from withdrawing back into the crucible. This first pressure level 110 is greater than the initial pressure applied to the liquefied metal. The pressure is then reduced to a lower pressure level 115. This lower pressure level 115 is still greater than the original pressure 105 applied to the liquefied metal. The pressure applied to the liquefied metal is then increased to a level 1.20 that is greater than the first pressure level 110. Again, these oscillating increasing pressure steps provide for a pulsating action upon the liquefied metal in order to breakdown the crystalline structure of the liquefied metal in the mold, thereby increasing its density. It should be appreciated that the magnitude of the slope of pressure increase is typically, but not necessarily greater than the magnitude of the slope of pressure decrease, thereby accentuating the impulses imparted upon the liquefied metal.

Figs. 9 through 12 are pictorial illustrations that depict alternative example pressure profiles useful in other molding methods.

Fig. 13 is a pictorial diagram that illustrates the structure of one example embodiment of a molding machine. According to this example embodiment, a molding machine comprises a crucible 200 disposed in a crucible chamber 205. The molding machine further comprises a differential pressure unit 210 that applies a differential pressure to a liquefied metal 204 contained in the crucible 200. In operation, a mold 217, included in one alternative embodiment of a molding machine, receives the liquefied metal 250 when a differential pressure is applied to said liquefied metal. The molding machine of this example embodiment further comprises a pressure controller 215. The pressure controller 215 controls the differential pressure unit 210 so as to increase the pressure applied to liquefied metal in the mold 250 in increasing oscillating pressure steps in accordance with the method taught herein.

Fig. 13 further illustrates that, according to one alternative example embodiment, the differential pressure unit 210 comprises a pressure unit 225, which is disposed to apply pressure to the crucible chamber 205. This is accomplished when the controller 215 opens a valve 260 enabling pressure from the pressure unit 225 to enter the crucible chamber 205. In an alternative embodiment, the differential pressure unit 210 comprises a vacuum unit 220 disposed to apply a vacuum to a mold chamber 247, which is included in this alternative example embodiment. In this alternative embodiment, the controller 215 controls a valve 222 that enables reduction in pressure in the mold chamber 247 by establishing a path from the mold chamber 247 to the vacuum unit 220.

[0008] In one alternative example embodiment, the differential pressure unit 210 comprises a gaseous pressure unit 225 which, under control of the controller 215, increases the applied differential pressure to a first increased level and then reduces the applied differential pressure to a level that is greater than the initially applied differential pressure. The controller 215 then causes the applied differential pressure to be increased to level that is greater than the first increased level in accordance with the techniques and teachings herein. In one alternative embodiment, an increase in the applied differential pressure to a first increased level is accomplished by controlling a valve 260 enabling pressure from the gaseous pressure unit 225 to be directed to the crucible chamber 205. In yet another alternative embodiment, an increase in the applied differential pressure to a first increased level is accomplished by controlling a valve 265 enabling pressure from the gaseous pressure unit 225 to be directed to the mold chamber 247. Again, the controller 215 controls either the valve 260 enabling an increase in pressure in the crucible chamber 205 or the valve 265 enabling an increase in pressure in the mold chamber 247 in a pulsating manner consistent with the teachings of the method herein described.

[0009] Fig. 13 also illustrates that, according to one alternative example embodiment, a molding machine further comprises a mechanical pressure actuator 230. The mechanical pressure actuator 230 receives work 240 and applies a proportionate amount of pressure to the liquefied metal contained in the mold 250. In one embodiment, the mechanical pressure actuator 230 includes a gate mechanism 233 that isolates the liquefied metal in that crucible chamber 245 from the liquefied metal in the mold 250. The mechanical pressure actuator 230 then applies work to the liquefied metal in the mold 250 so as to increase the pressure therein to a first level that is greater than the pressure applied to liquefied metal by the differential pressure unit 210. The mechanical pressure actuator then reduces the work (i.e. pressure) applied to liquefied metal so as to reduce the pressure in the liquefied metal to a level that is greater than the pressure applied to liquefied metal by the differential pressure unit 210.

[0010] The mechanical pressure actuator 230 then applies more work to the liquefied metal in order to increase the pressure applied to the liquefied metal to a second level that is greater than the first pressure level applied to the liquefied metal by the mechanical pressure actuator 230. It should be appreciated that, in this alternative example embodiment, the controller 215 controls an mechanical actuator 260 that creates physical work 240 that is applied to the mechanical pressure actuator 235. Again, controller 215 controls the amount of applied work 240 accordance with the techniques and teachings herein described chose results in an increase in the pressure of the liquefied metal 250 in the mold in increasing oscillating pressure steps. In one example embodiment, the actuator comprises a solenoid, but this is merely an example embodiment that is not intended to limit scope of the claims appended hereto.

[0011] Fig. 13 further illustrates that, according to yet another alternative embodiment, the work created by the mechanical actuator 260 is applied to a pressure ram 241. The pressure ram 241 conveys the physical work directly to the liquefied metal contained within the mold itself. In various alternative embodiments, a plurality of such pressure rams 241 are situated at various locations and penetrate the mold at varying angles. The quantity and placement of such pressure rams 241 is typically established by empirical experimentation so as to determine the most effective resultant component created in the mold. The measure is the most effective resultant component is typically driven by the density of the solidified metal throughout various regions within the resultant component.

[0012] Fig. 14 is a pictorial illustration of an alternative example embodiment of a molding machine that includes the gate valve for isolating liquefied metal in the mold from the crucible. In this alternative example embodiment, the mechanical pressure actuator 235 does not include a gate mechanism. In lieu of the gate mechanism, this alternative embodiment provides a gate valve 280 that is used to isolate the liquefied metal 250 in the mold from the liquefied metal 245 in the crucible. Control of the gate valve 280 is accomplished by the controller 215 and a sequencer that enables isolation prior to application of work to the mechanical pressure actuator 235 as heretofore described. In one embodiment, a solenoid 285 is used to actuate the gate valve 280.

[0013] Its should also be appreciated that the applicant herein also claims molded products that are produced in accordance with the manufacturing method, at all variations thereof, herein described.

[0014] While the present method and apparatus has been described in terms of several alternative and exemplary embodiments, it is contemplated that alternatives, modifications, permutations, and equivalents thereof will become apparent to those skilled in the art upon a reading of the specification and study of the drawings. It is therefore intended that the true spirit and scope of the claims appended hereto include all such alternatives, modifications, permutations, and equivalents.

Claims

1. [Claim_M_A]A method for pulsed pressure molding comprising: liquefying a metal in a crucible disposed in a crucible chamber; applying a differential pressure level to the liquefied metal so as to force the liquefied metal into a mold; raising the pressure of the liquefied metal in the mold to a solidification pressure in oscillating pressure steps; and allowing the liquefied metal to solidify.

2. The method of Claim 1, wherein applying a differential pressure to the liquefied metal comprises increasing the pressure in a crucible chamber.

3. The method of Claim 1, wherein applying a differential pressure to the liquefied metal comprises decreasing the pressure in a mold chamber.

4. The method of Claim 1, wherein raising the pressure of the liquefied metal in oscillating steps comprises: applying a gaseous pressure at a first level to the liquefied metal in the mold wherein the first pressure level is greater than the applied differential pressure; reducing the gaseous pressure level to a level that is still greater than the applied differential pressure; and increasing the gaseous pressure level to a second level that is greater than the first gaseous pressure level.

5. The method of Claim 4, wherein applying a gaseous pressure comprises applying a gaseous pressure to either of the mold chamber or the crucible chamber.

6. The method of Claim 1 wherein raising the pressure of the liquefied metal in oscillating steps comprises: isolating the liquefied metal in the crucible chamber from the liquefied metal in the mold; applying a mechanical pressure at a first level to the liquefied metal in the mold wherein the first mechanical pressure level is greater than the applied differential pressure; reducing the mechanical pressure level to a level that is still greater than the applied differential pressure ; and increasing the mechanical pressure level to a second level that is greater than the first mechanical pressure level.

7. A pulsed pressure molding machine comprising: crucible disposed in a crucible chamber; differential pressure unit for applying a differential pressure to a liquefied metal disposed in the crucible; mold that receives the liquefied metal when a differential pressure is applied to the liquefied metal; and pressure controller that controls the pressure unit so as to increase the pressure applied to the liquefied metal in increasing oscillating pressure steps.

8. The molding machine of Claim 7 wherein the differential pressure unit comprises a pressure unit disposed to apply pressure to the crucible chamber.

9. The molding machine of Claim 7 wherein mold is disposed in a mold chamber and the differential pressure unit comprises a vacuum unit disposed to apply a vacuum to the mold chamber.

10. The molding machine of Claim 7 wherein the differential pressure unit comprises a gaseous pressure unit and the controller causes the differential pressure unit to: - increase the applied differential pressure to a first increased level; reduce the applied differential pressure to a level that is greater than the initially applied differential pressure; and increase the applied differential pressure to a level that is greater that the first increased level.

11. The molding machine of Claim 10 wherein the gaseous pressure unit is disposed to apply a positive pressure to the crucible chamber.

12. The molding machine of Claim 10 further comprising a mold chamber for containing the mold and wherein the gaseous pressure unit is disposed to apply a positive pressure to the mold chamber.

13. The molding machine of Claim 10 further comprising a mechanical pressure actuator for applying mechanical pressure to the liquefied metal and wherein the mechanical pressure actuator is disposed to isolate liquefied metal contained in the crucible chamber from the liquefied metal contained in the mold and wherein the pressure controller causes the mechanical pressure actuator to: apply work to the liquefied metal in the mold so as to cause an increase in pressure therein to a first level that is greater than the pressure applied to the liquefied metal by the differential pressure unit; reduce the work applied to the liquefied metal in the mold so as to reduce the pressure therein to a level that is greater than the pressure applied to the liquefied metal by the differential pressure unit; and apply work to the liquefied metal in the mold so as to cause an increase in pressure therein to a second level that is greater than the first pressure level applied to the liquefied metal by the mechanical actuator.

14. The molding machine of Claim 10 further comprising a mechanical pressure actuator for applying mechanical pressure to the liquefied metal and an isolator gate and wherein the isolator gate is disposed to isolate liquefied metal contained in the crucible chamber from the liquefied metal contained in the mold and wherein the pressure controller causes the mechanical pressure actuator to: apply work to the liquefied metal in the mold so as to cause an increase in pressure therein to a first level that is greater than the pressure applied to the liquefied metal by the differential pressure unit; reduce the work applied to the liquefied metal in the mold so as to reduce the pressure therein to a level that is greater than the pressure applied to the liquefied metal by the differential pressure unit; and apply work to the liquefied metal in the mold so as to cause an increase in pressure therein to a second level that is greater than the first pressure level applied to the liquefied metal by the mechanical actuator.

15. A molded product manufactured by a molding process that comprises: liquefying a metal; applying a differential pressure level to the liquefied metal so as to force the liquefied metal into a mold; raising the pressure of the liquefied metal in the mold to a solidification pressure in oscillating pressure steps; and allowing the liquefied metal to solidify.

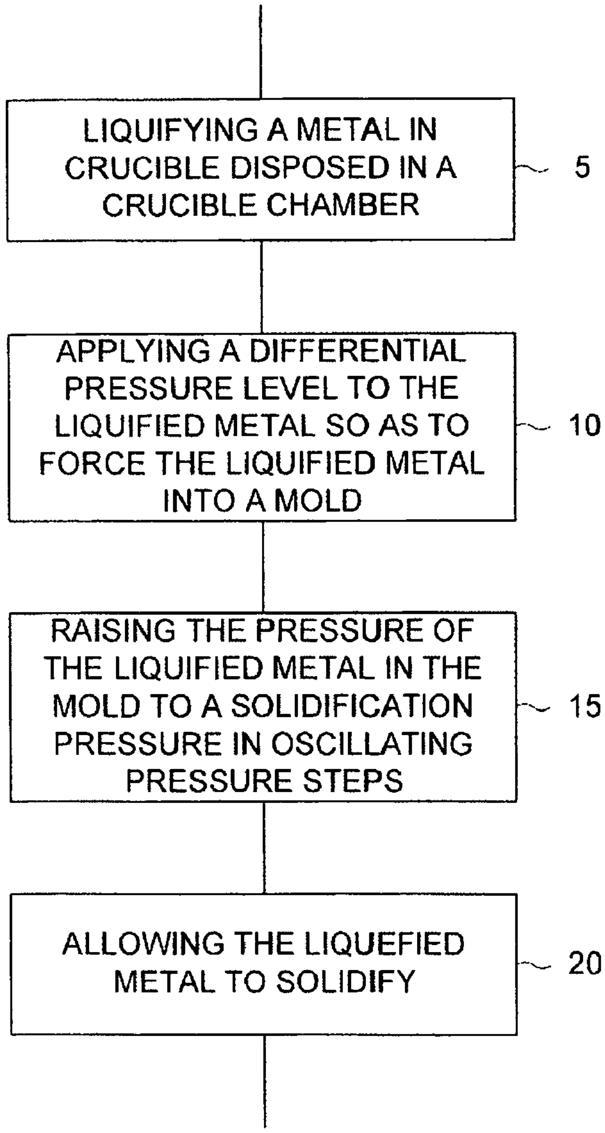
LIQUIFYING A METAL IN CRUCIBLE DISPOSED IN A CRUCIBLE CHAMBER
5
APPLYING A DIFFERENTIAL PRESSURE LEVEL TO THE LIQUIFIED METAL SO AS TO FORCE THE LIQUIFIED METAL INTO A MOLD
10
RAISING THE PRESSURE OF THE LIQUIFIED METAL IN THE MOLD TO A SOLIDIFICATION PRESSURE IN OSCILLATING PRESSURE STEPS
15
ALLOWING THE LIQUEFIED METAL TO SOLIDIFY
20

FIG. 1

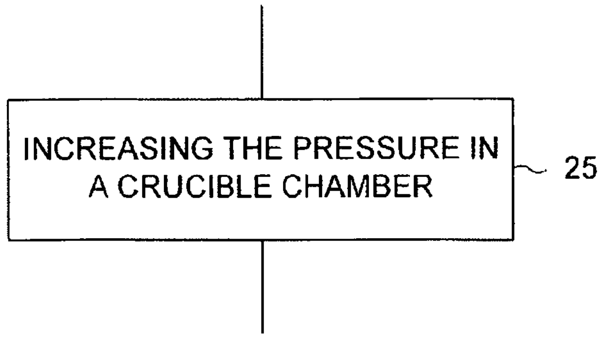
INCREASING THE PRESSURE IN A CRUCIBLE CHAMBER
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FIG. 2

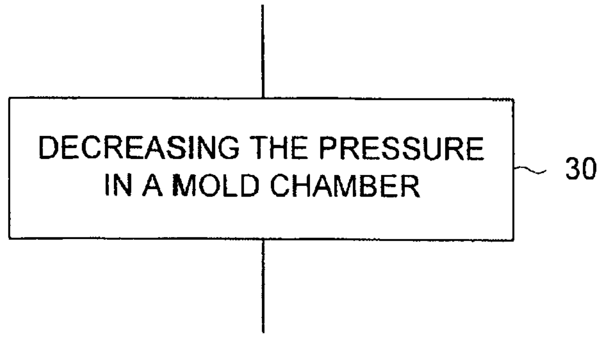
DECREASING THE PRESSURE IN A MOLD CHAMBER
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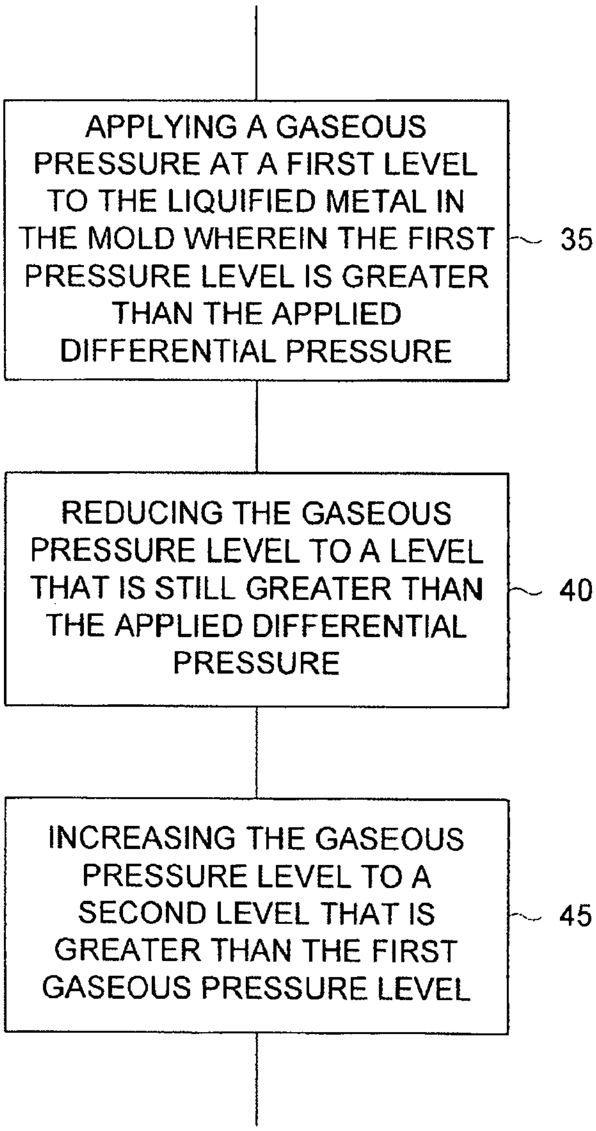
FIG. 3


APPLYING A GASEOUS PRESSURE AT A FIRST LEVEL TO THE LIQUIFIED METAL IN THE MOLD WHEREIN THE FIRST PRESSURE LEVEL IS GREATER THAN THE APPLIED DIFFERENTIAL PRESSURE
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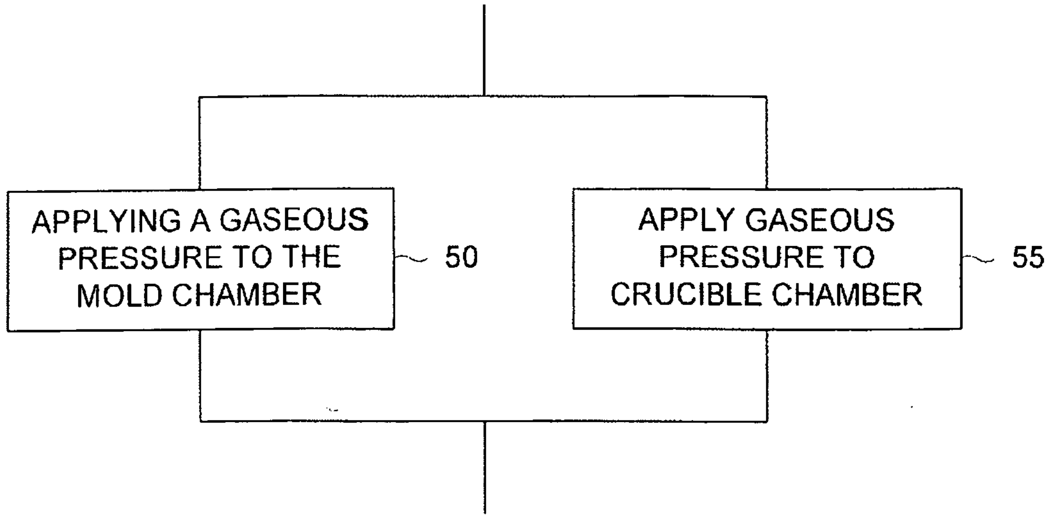
REDUCING THE GASEOUS PRESSURE LEVEL TO A LEVEL THAT IS STILL GREATER THAN THE APPLIED DIFFERENTIAL PRESSURE
40
INCREASING THE GASEOUS PRESSURE LEVEL TO A SECOND LEVEL THAT IS GREATER THAN THE FIRST GASEOUS PRESSURE LEVEL
45

FIG. 4


APPLYING A GASEOUS PRESSURE TO THE MOLD CHAMBER
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APPLY GASEOUS PRESSURE TO CRUCIBLE CHAMBER
55

FIG. 5

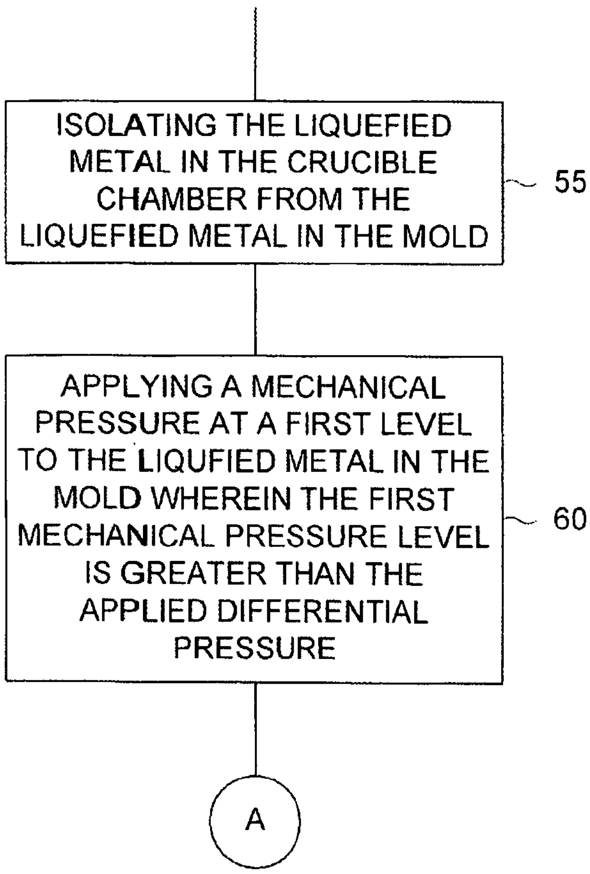
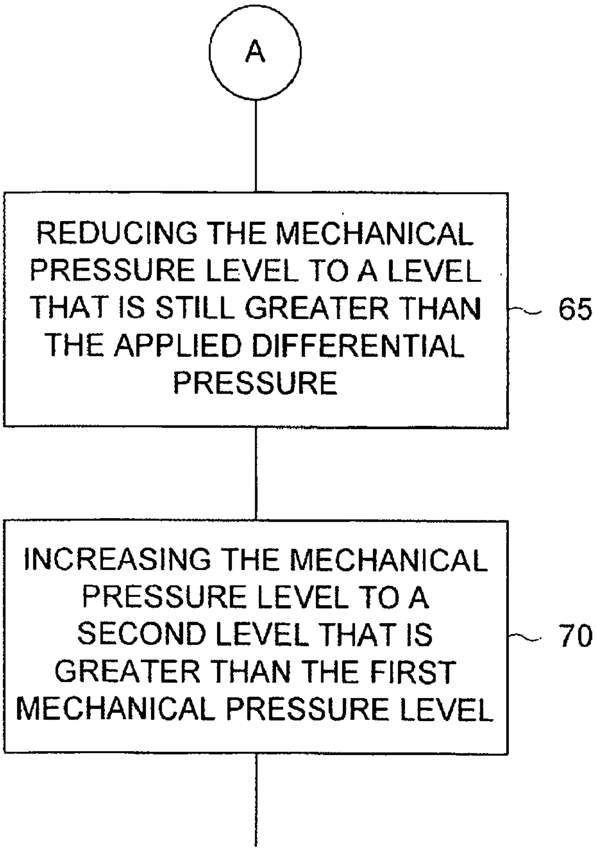

ISOLATING THE LIQUEFIED METAL IN THE CRUCIBLE CHAMBER FROM THE LIQUEFIED METAL IN THE MOLD
55
APPLYING A MECHANICAL PRESSURE AT A FIRST LEVEL TO THE LIQUFIED METAL IN THE MOLD WHEREIN THE FIRST MECHANICAL PRESSURE LEVEL IS GREATER THAN THE APPLIED DIFFERENTIAL PRESSURE
60
A

FIG. 6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REDUCING THE MECHANICAL PRESSURE LEVEL TO A LEVEL THAT IS STILL GREATER THAN THE APPLIED DIFFERENTIAL PRESSURE
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INCREASING THE MECHANICAL PRESSURE LEVEL TO A SECOND LEVEL THAT IS GREATER THAN THE FIRST MECHANICAL PRESSURE LEVEL
70

FIG. 7

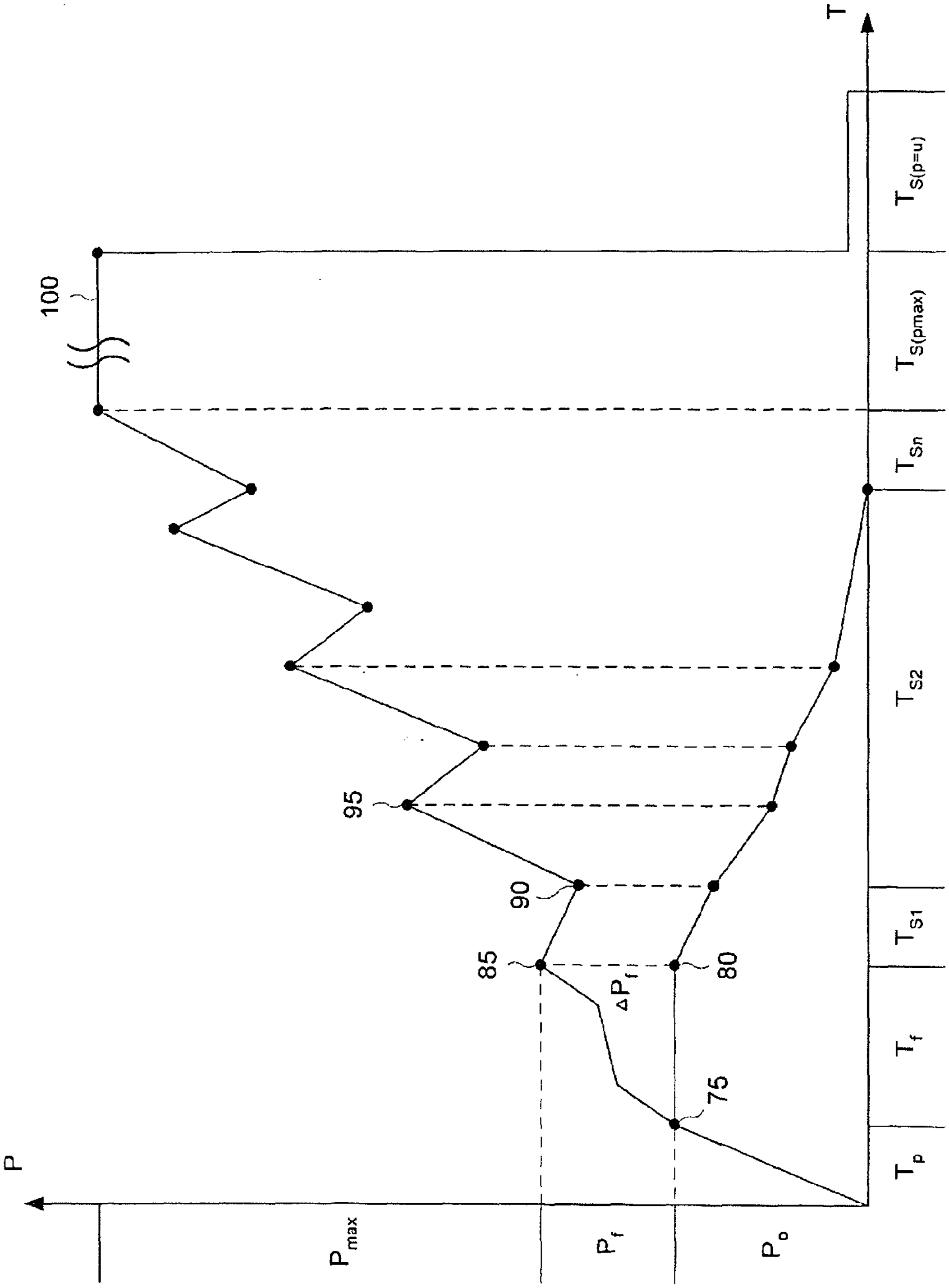


FIG. 7A

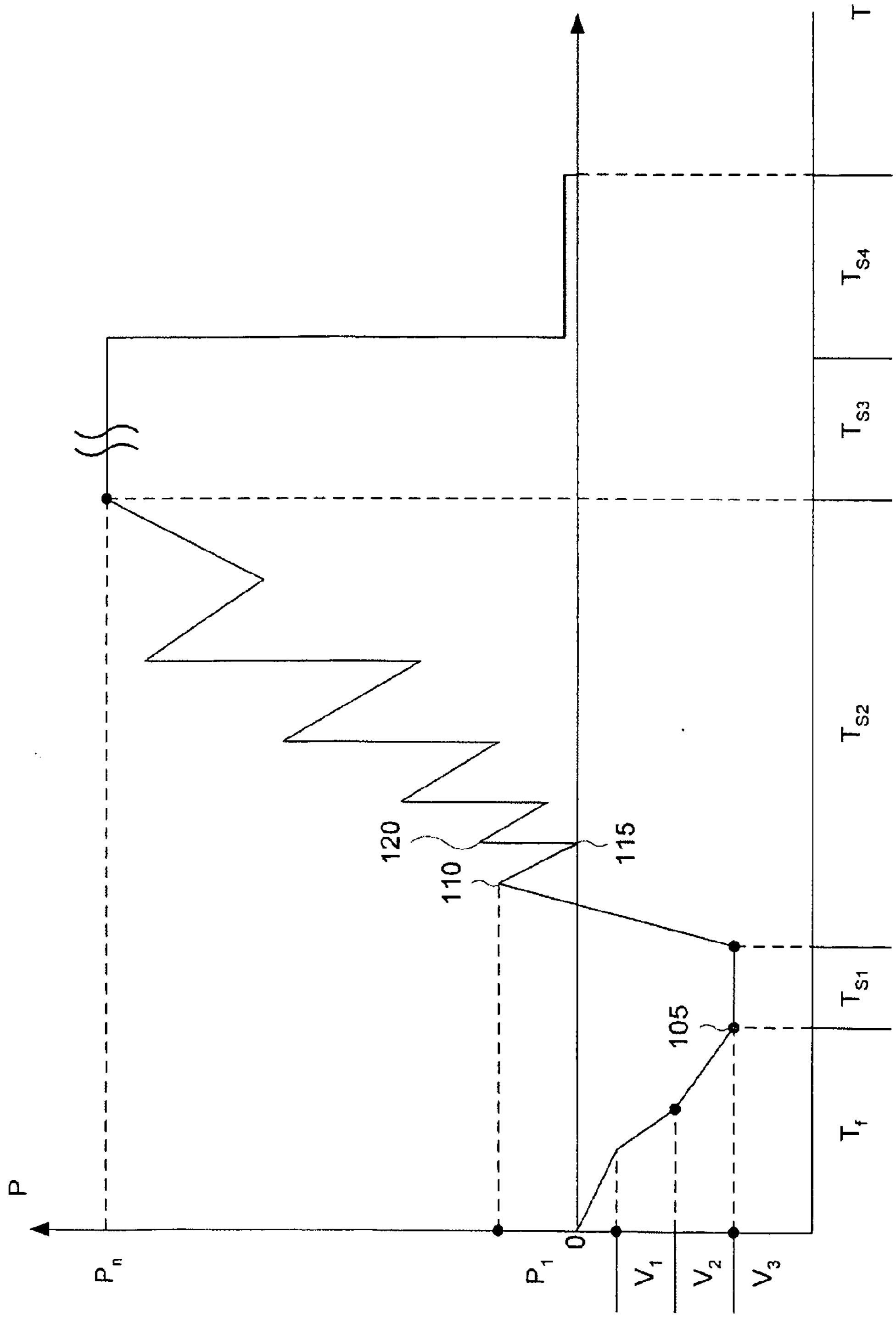


FIG. 8

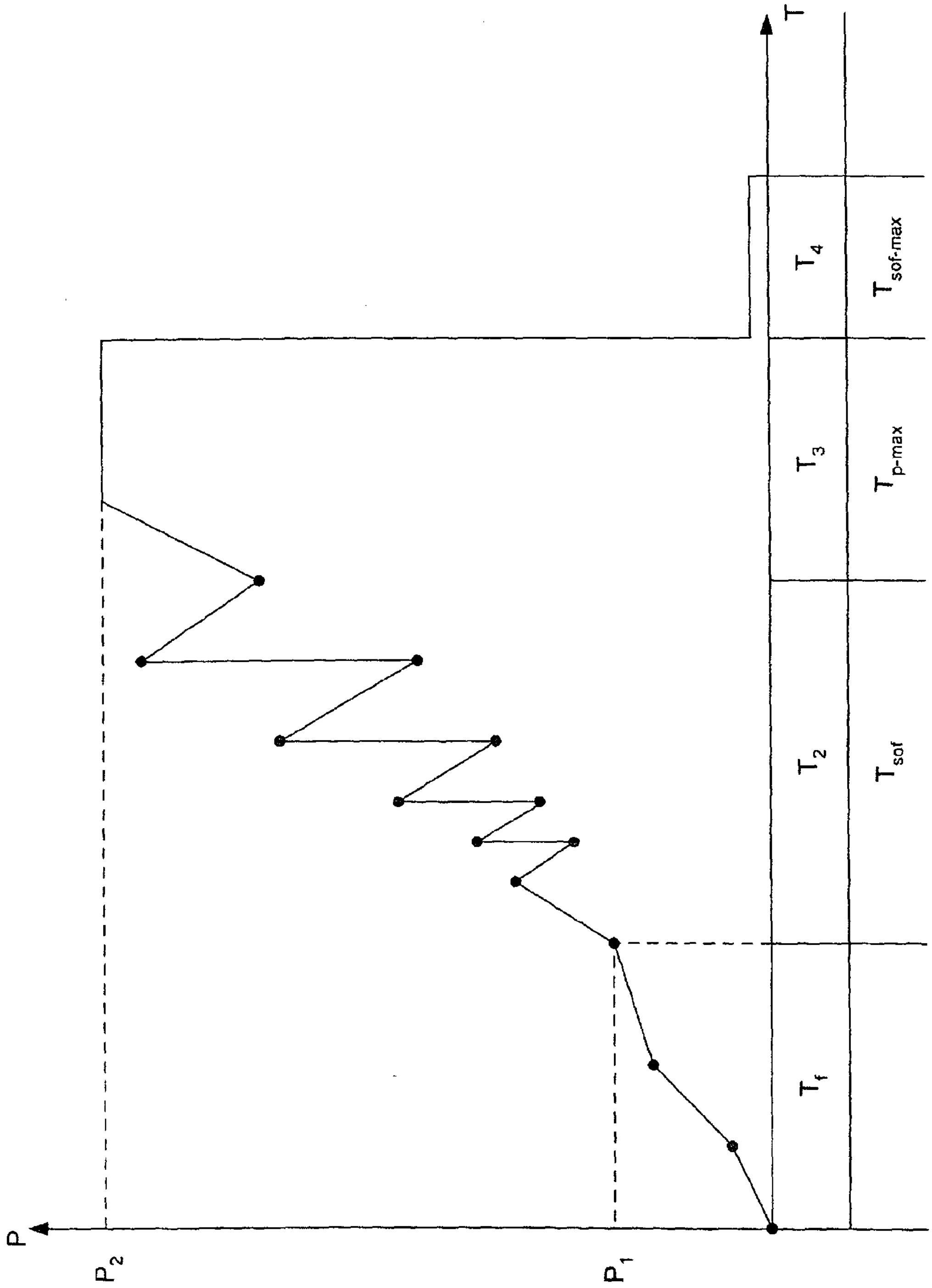


FIG. 9

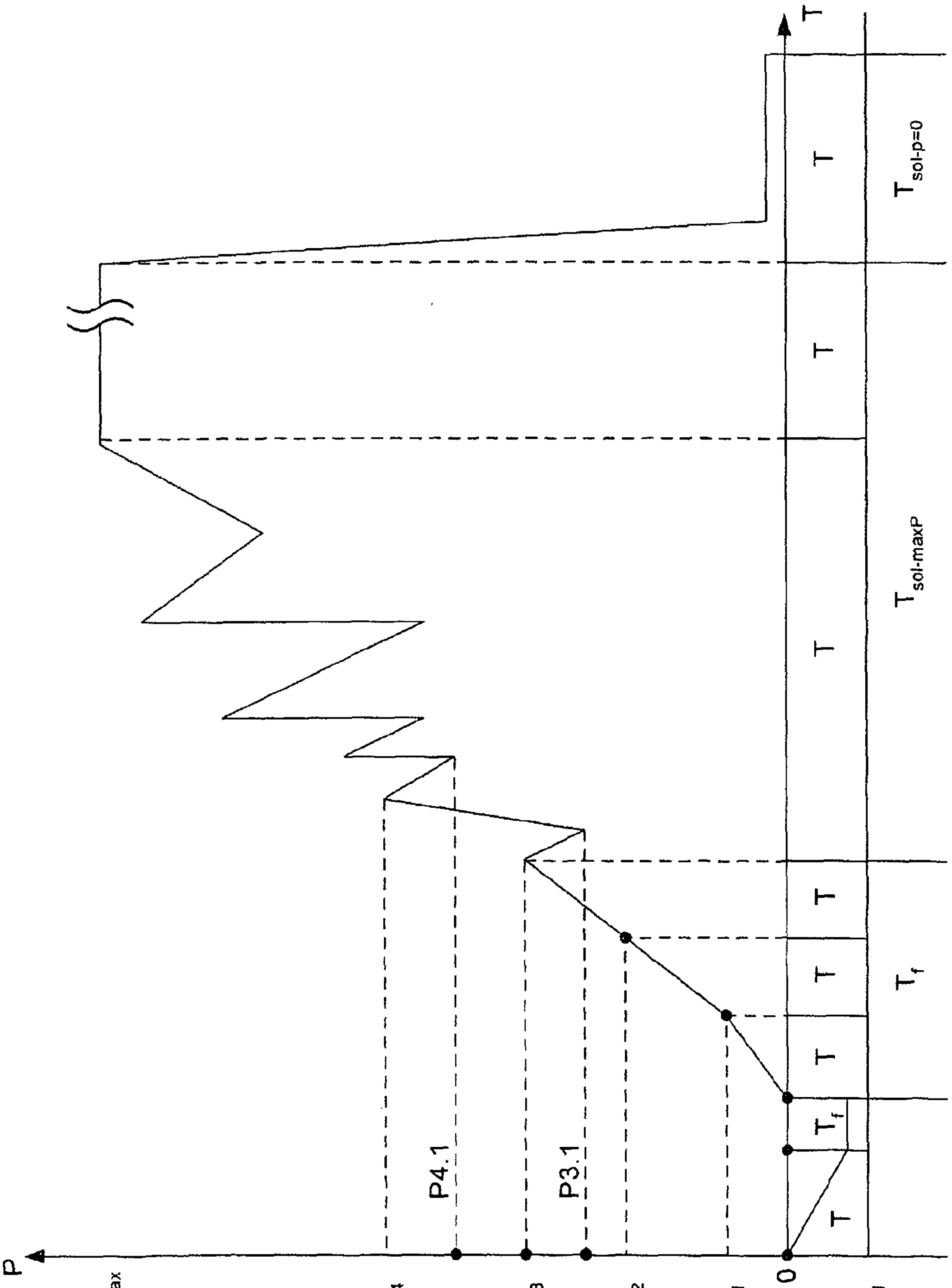


FIG. 10

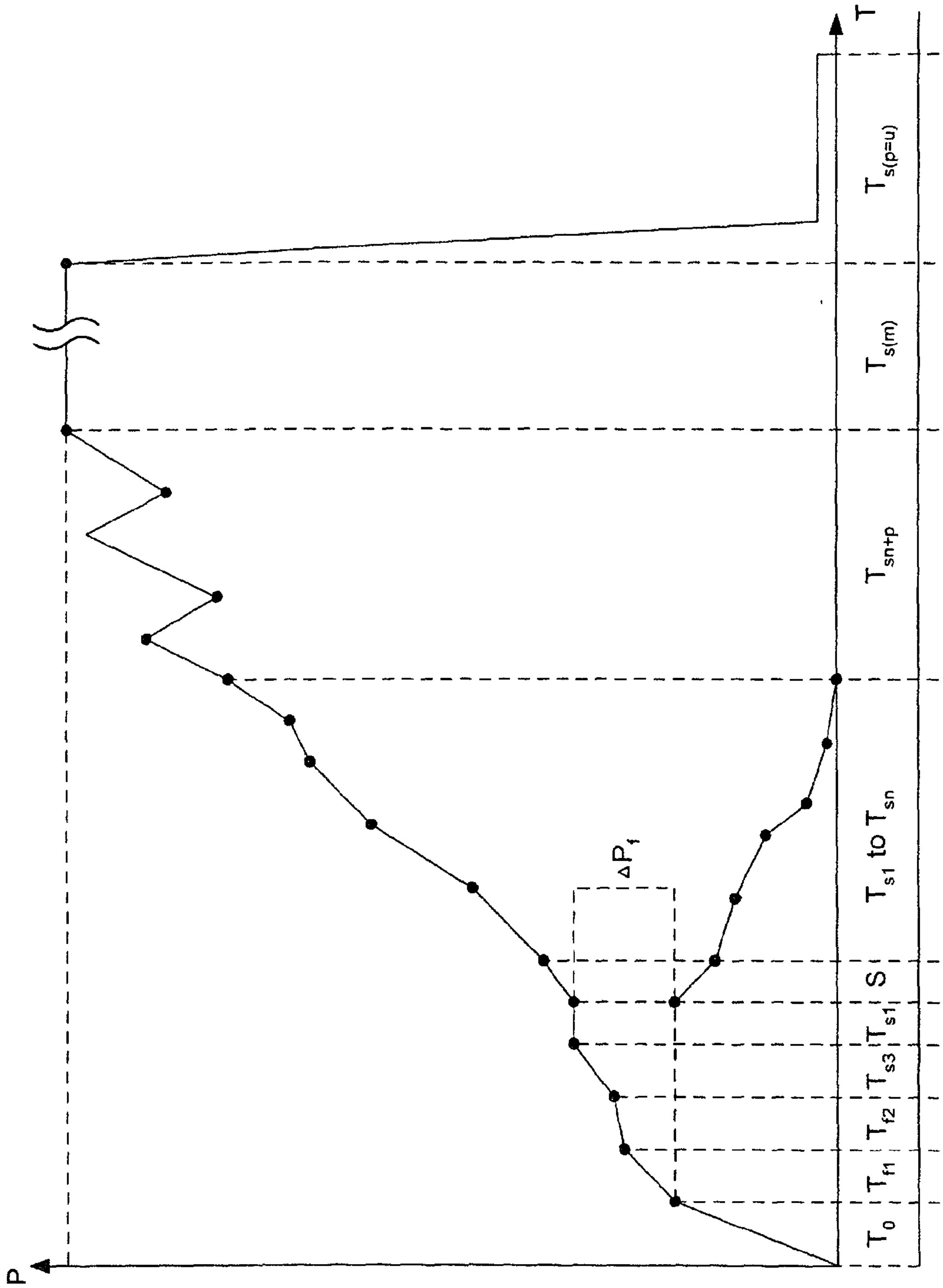


FIG. 11

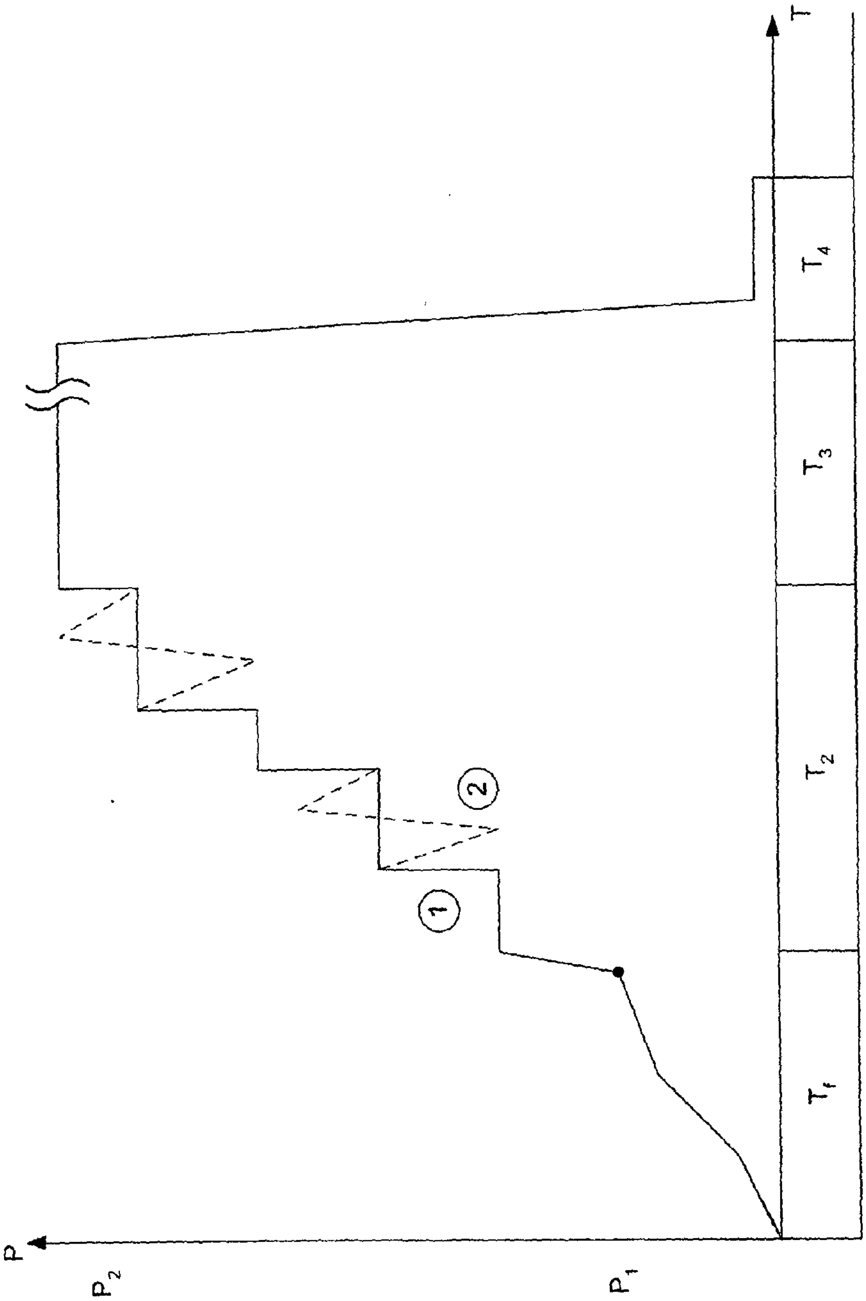
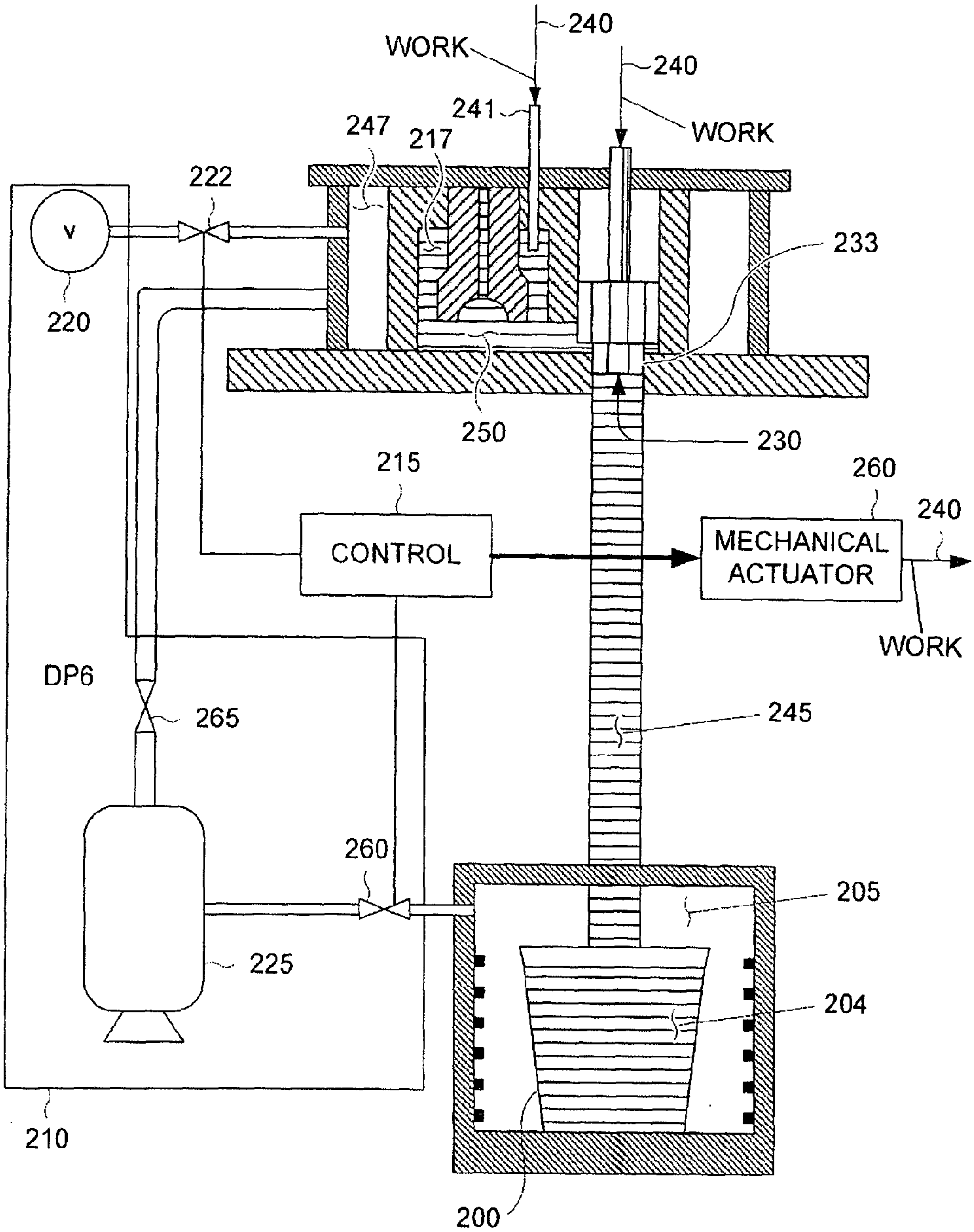


FIG. 12


240
WORK
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222
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V
220
250
230
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CONTROL
MECHANICAL
ACTUATOR
WORK
DP6
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245
260
205
225
204
210
200

FIG. 13

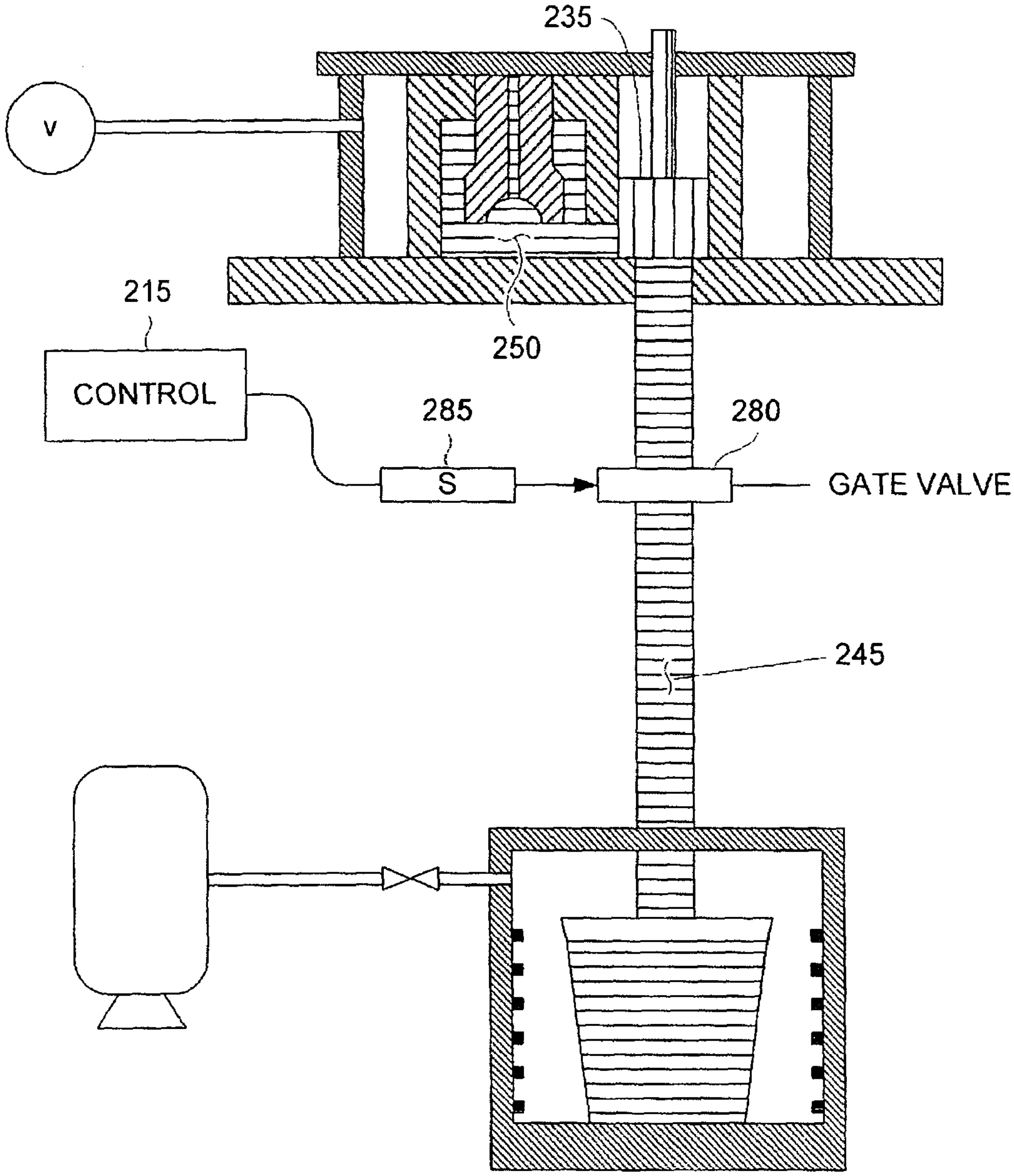

FIG. 14

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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