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(54) VERTICAL HEAT TREATMENT SYSTEM

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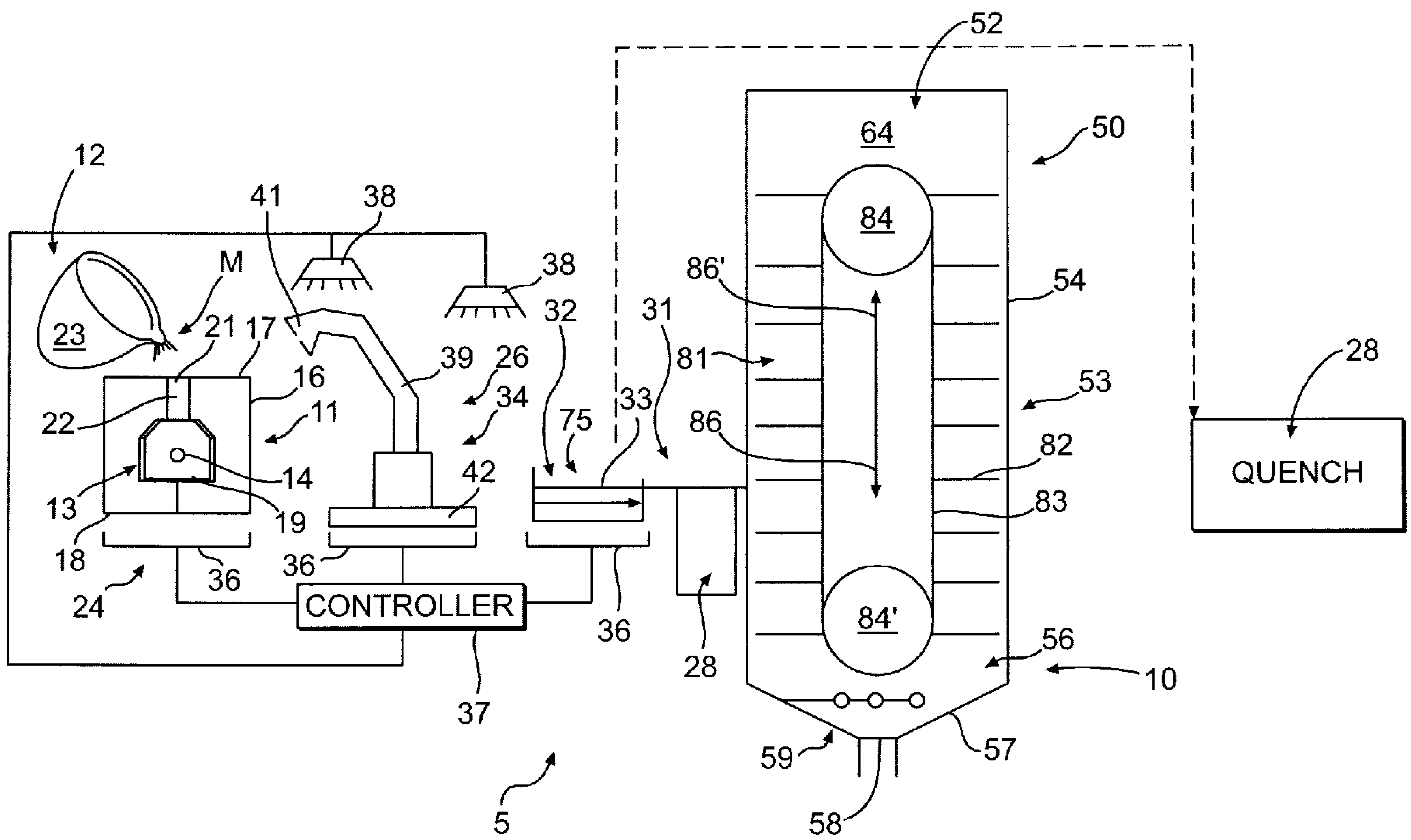
(57) ABSTRACT

A system and method for forming and heat treating metal castings is provided with a vertical heat treatment unit positioned adjacent and downstream from a pouring station at which a series of molds are filled with a molten metal to form the castings. The vertical heat treatment unit includes a vertically oriented furnace chamber in which the castings are received, and which has a reduced footprint to reduce the manufacturing floor space required for the vertical heat treatment unit, and to enable the vertical heat treatment unit to be positioned in close proximity to the pouring station.



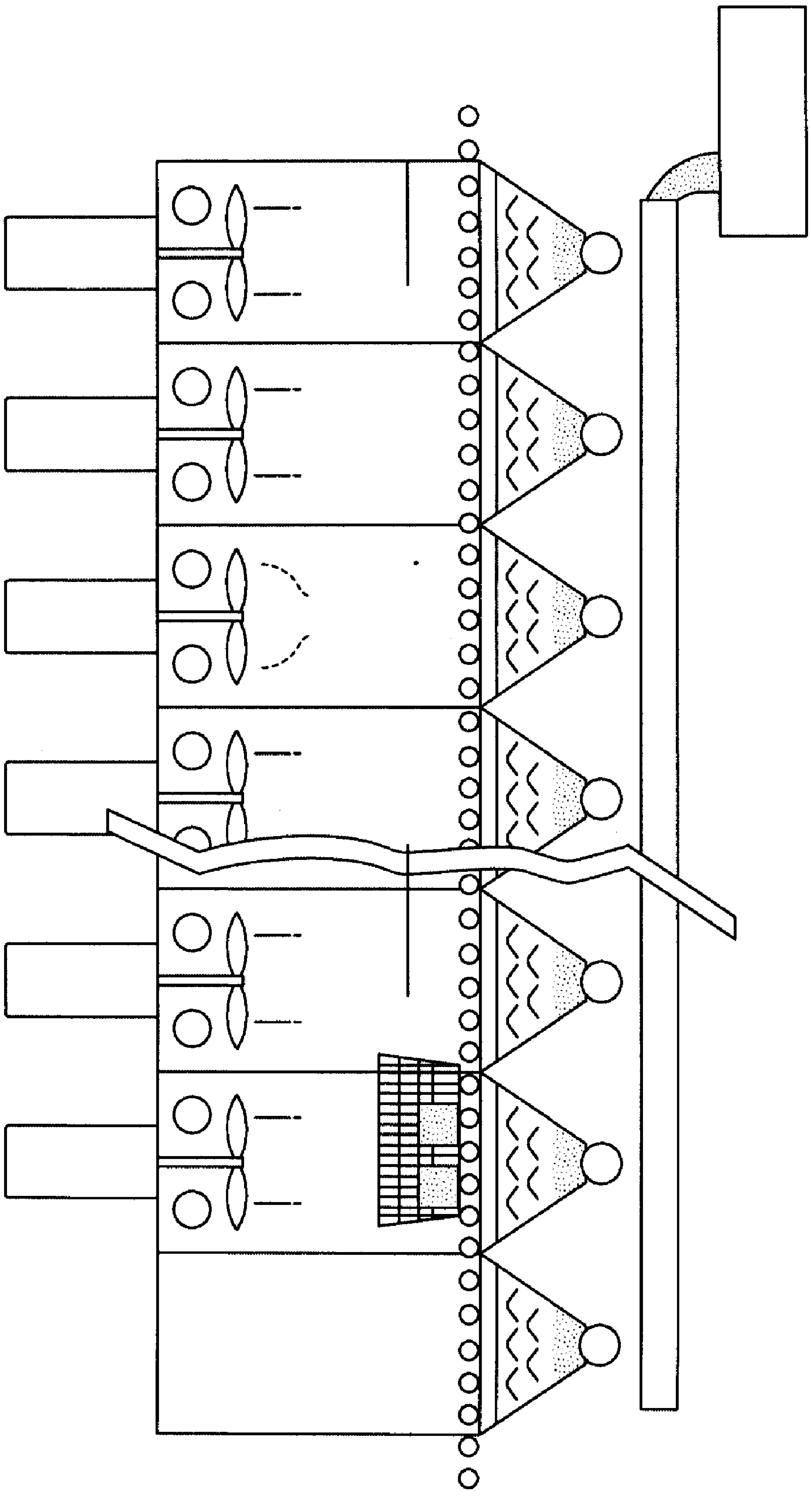


FIG. 1A
PRIOR ART

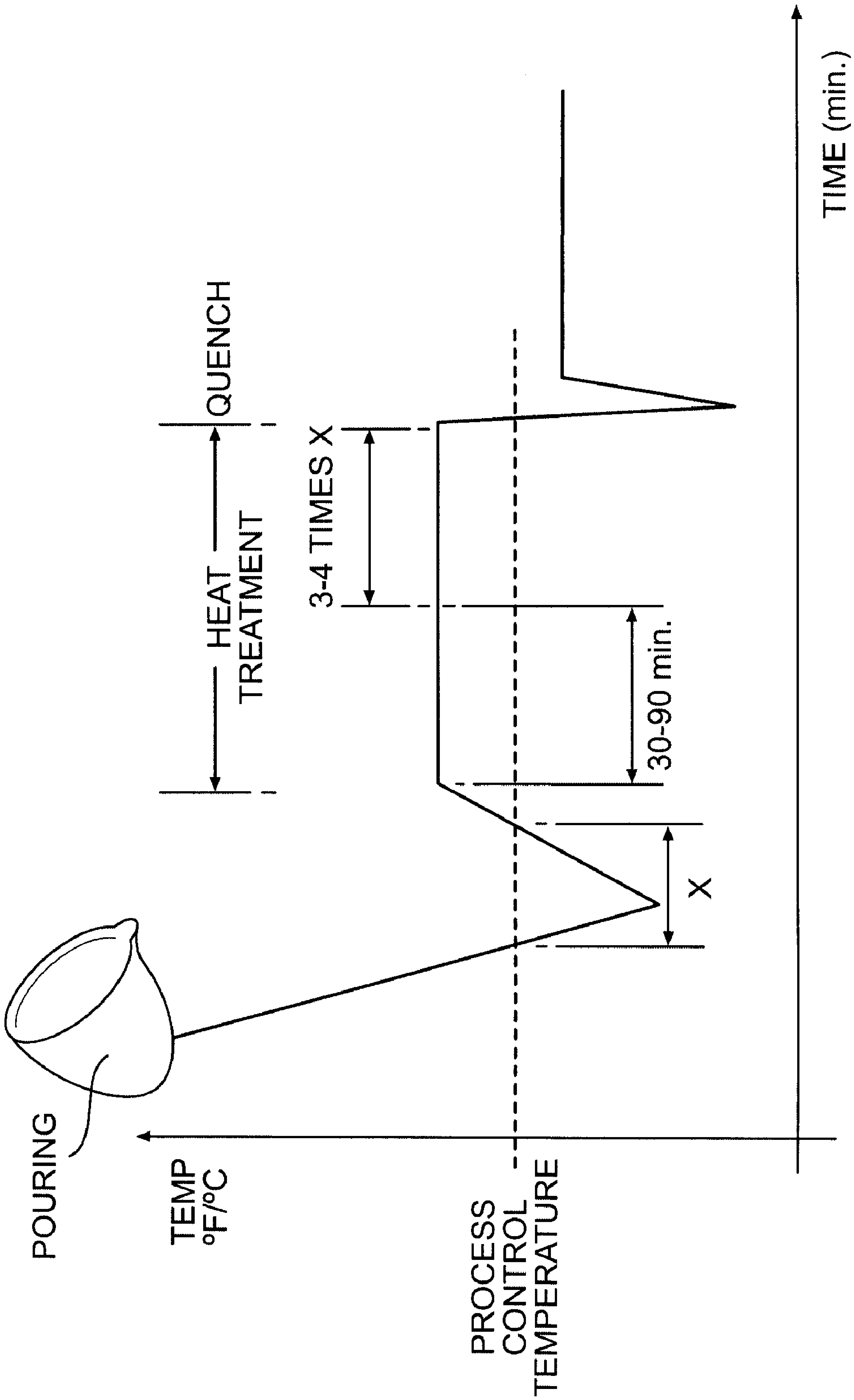


FIG. 1B
PRIOR ART

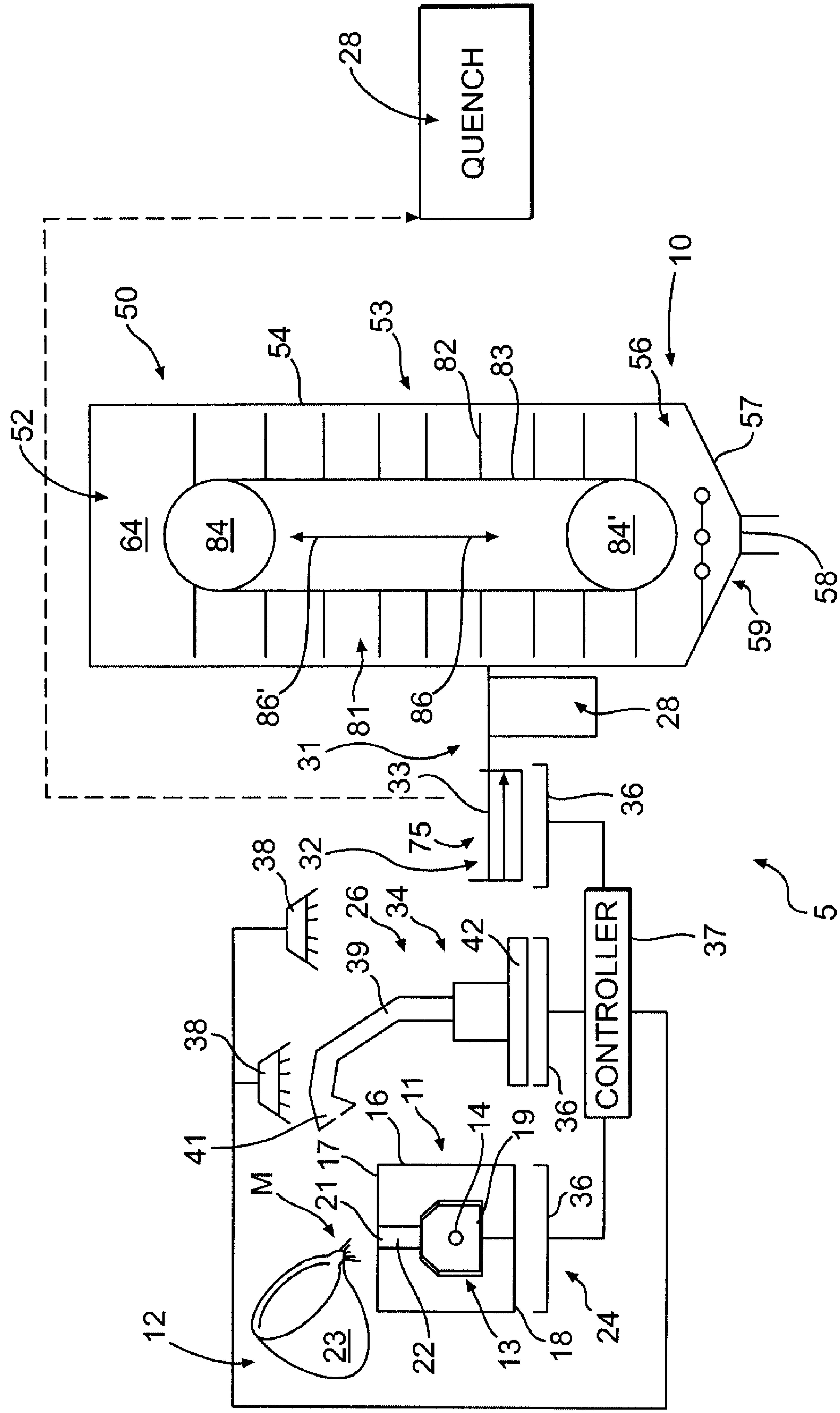

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FIG. 2A

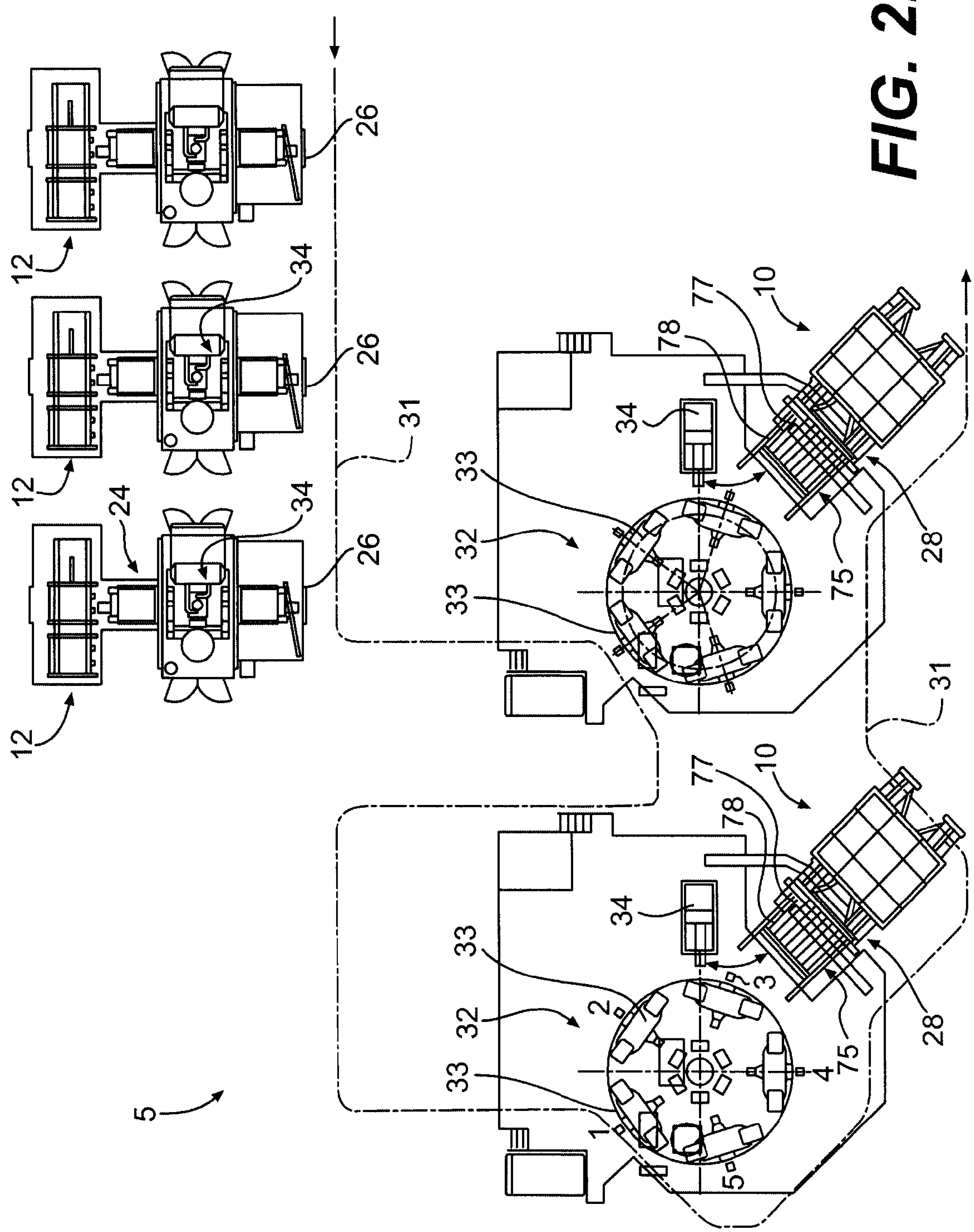

FIG. 2B

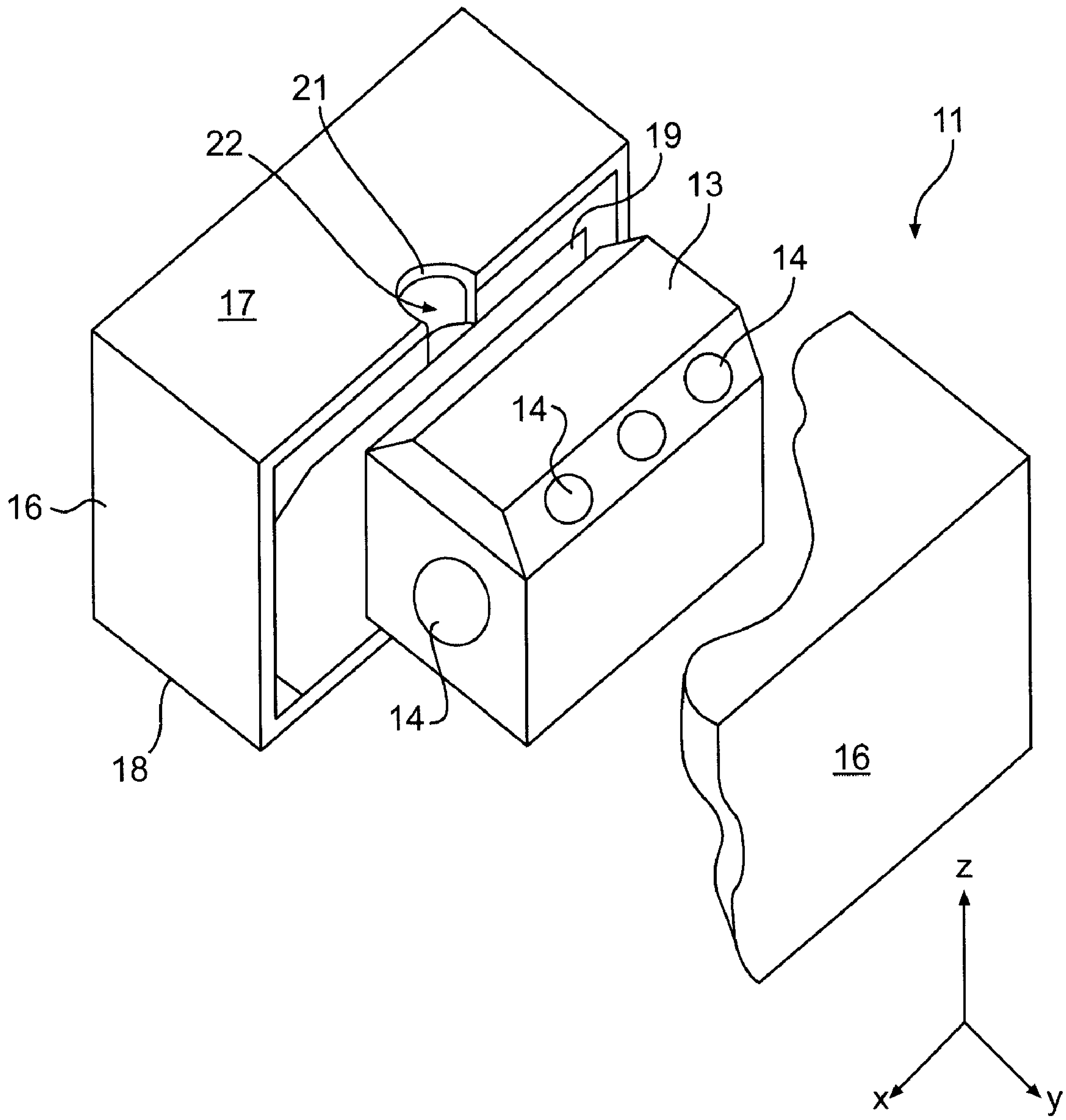

FIG. 3

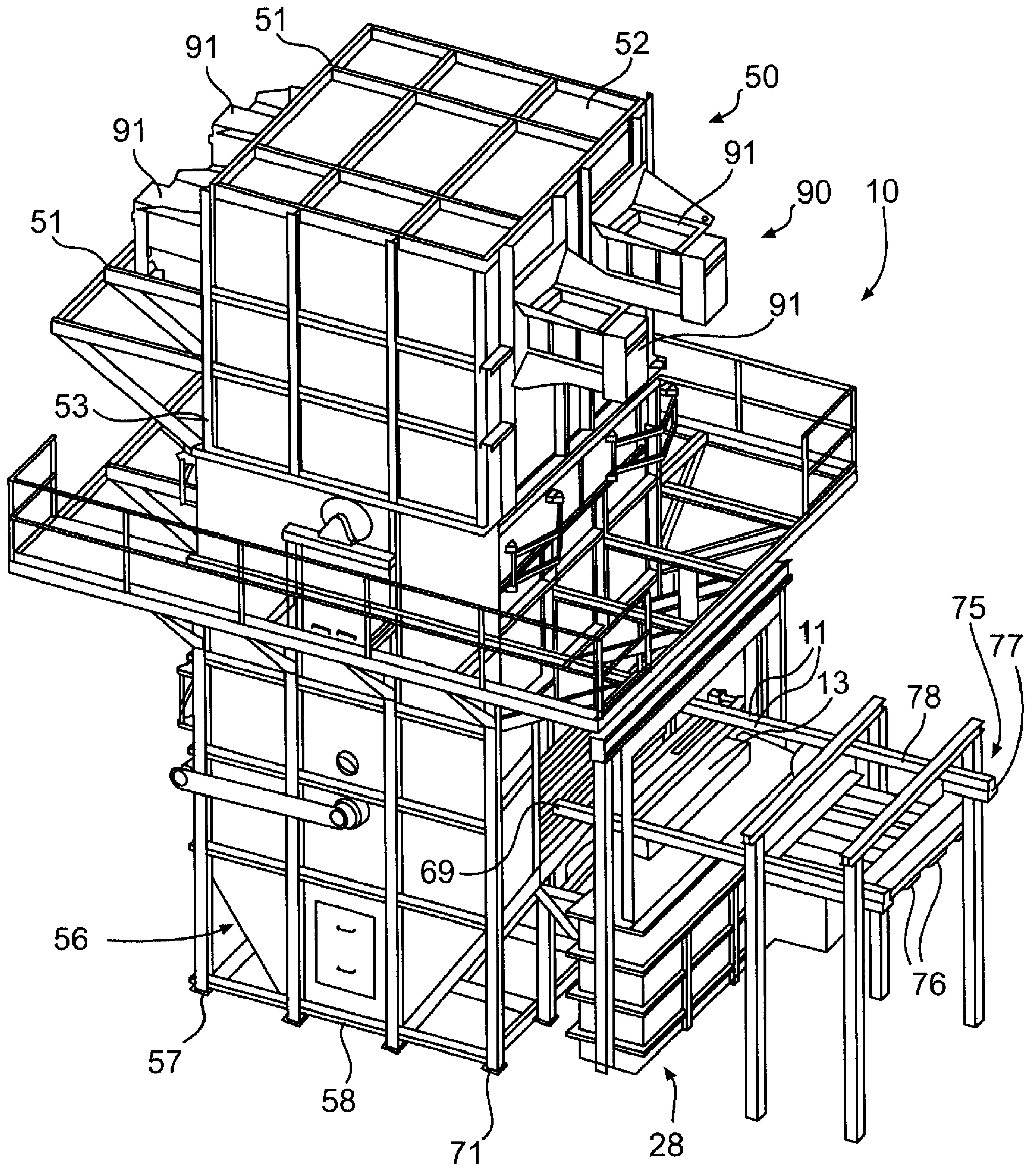

FIG. 4

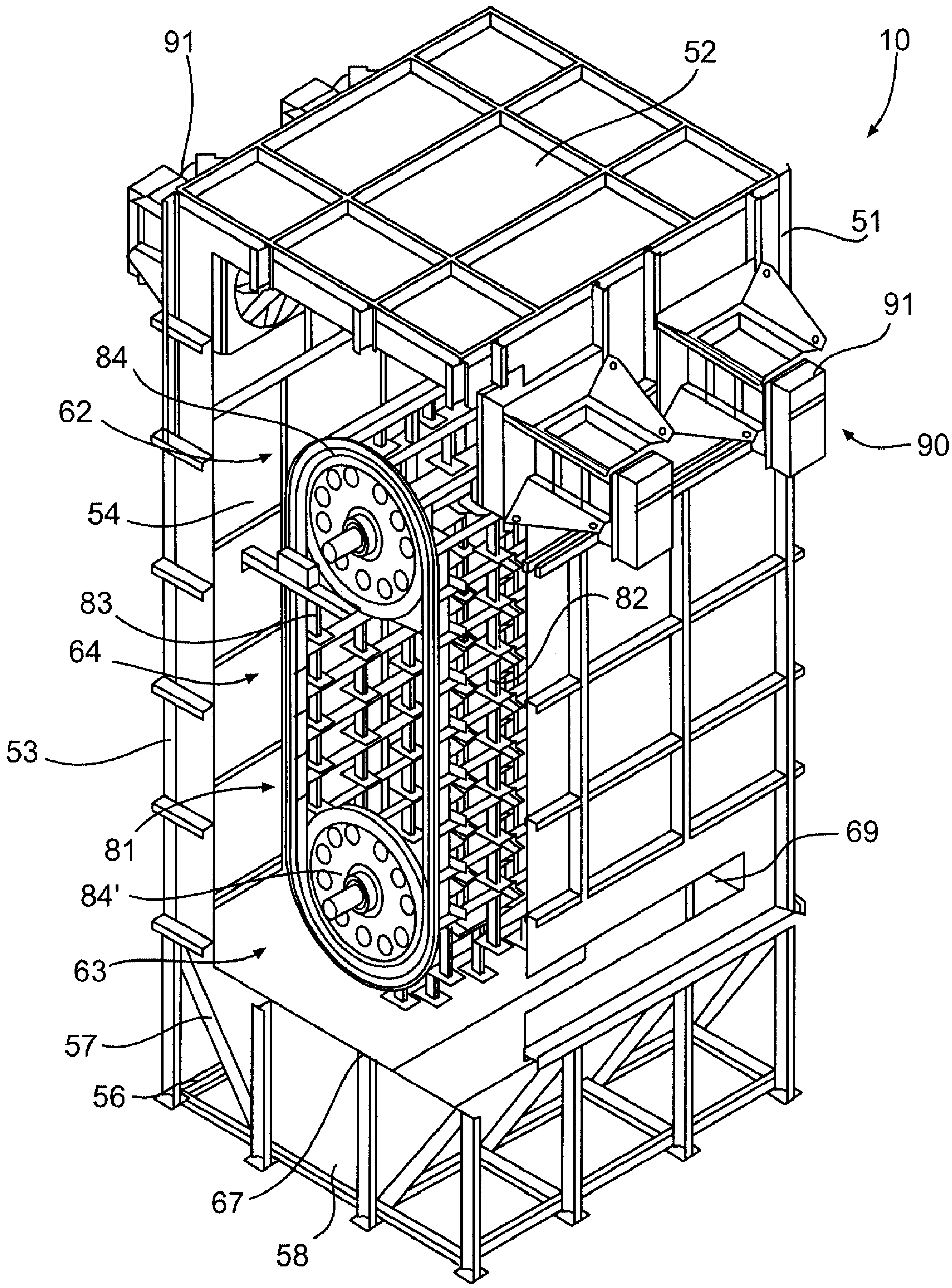

FIG. 5A

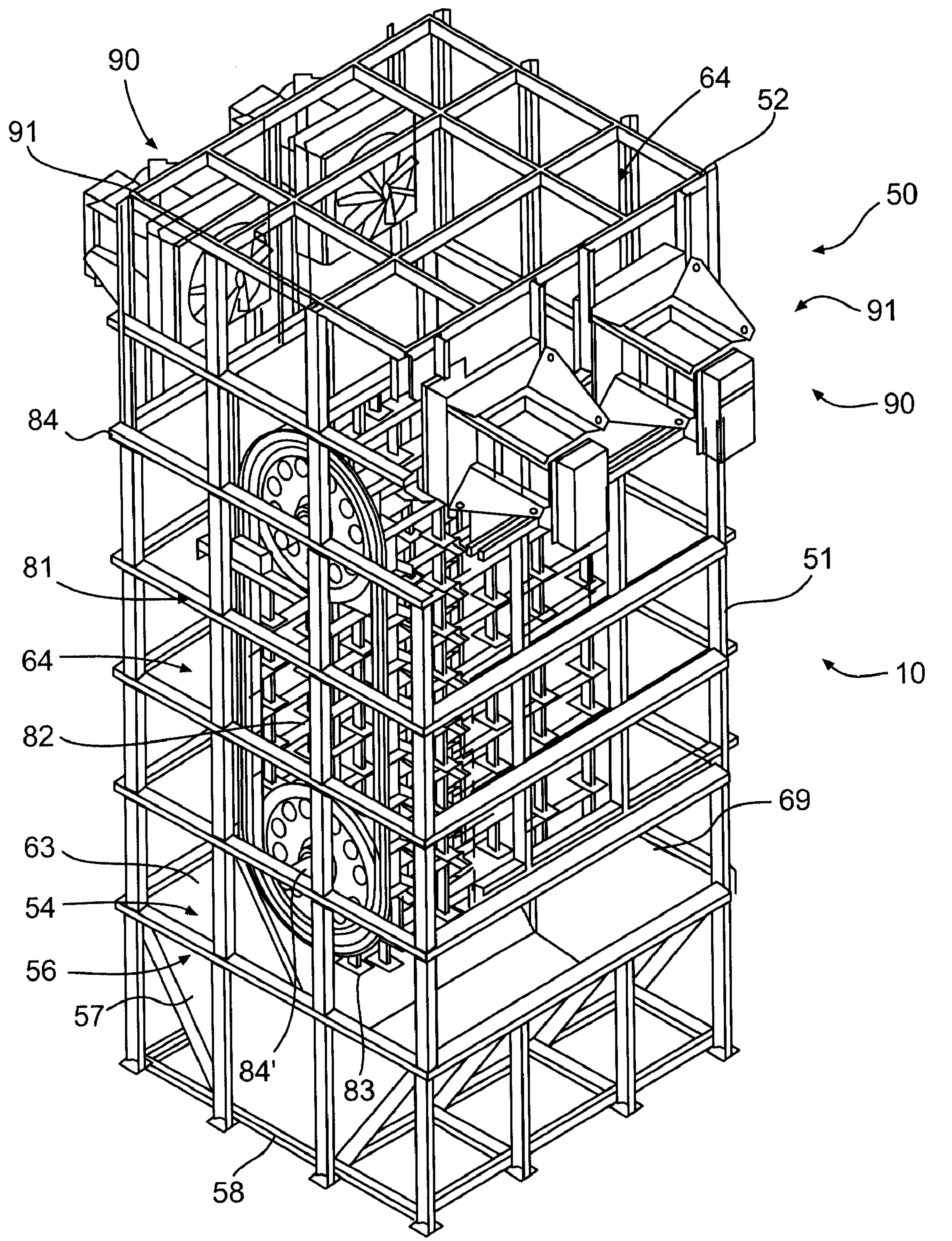

FIG. 5B

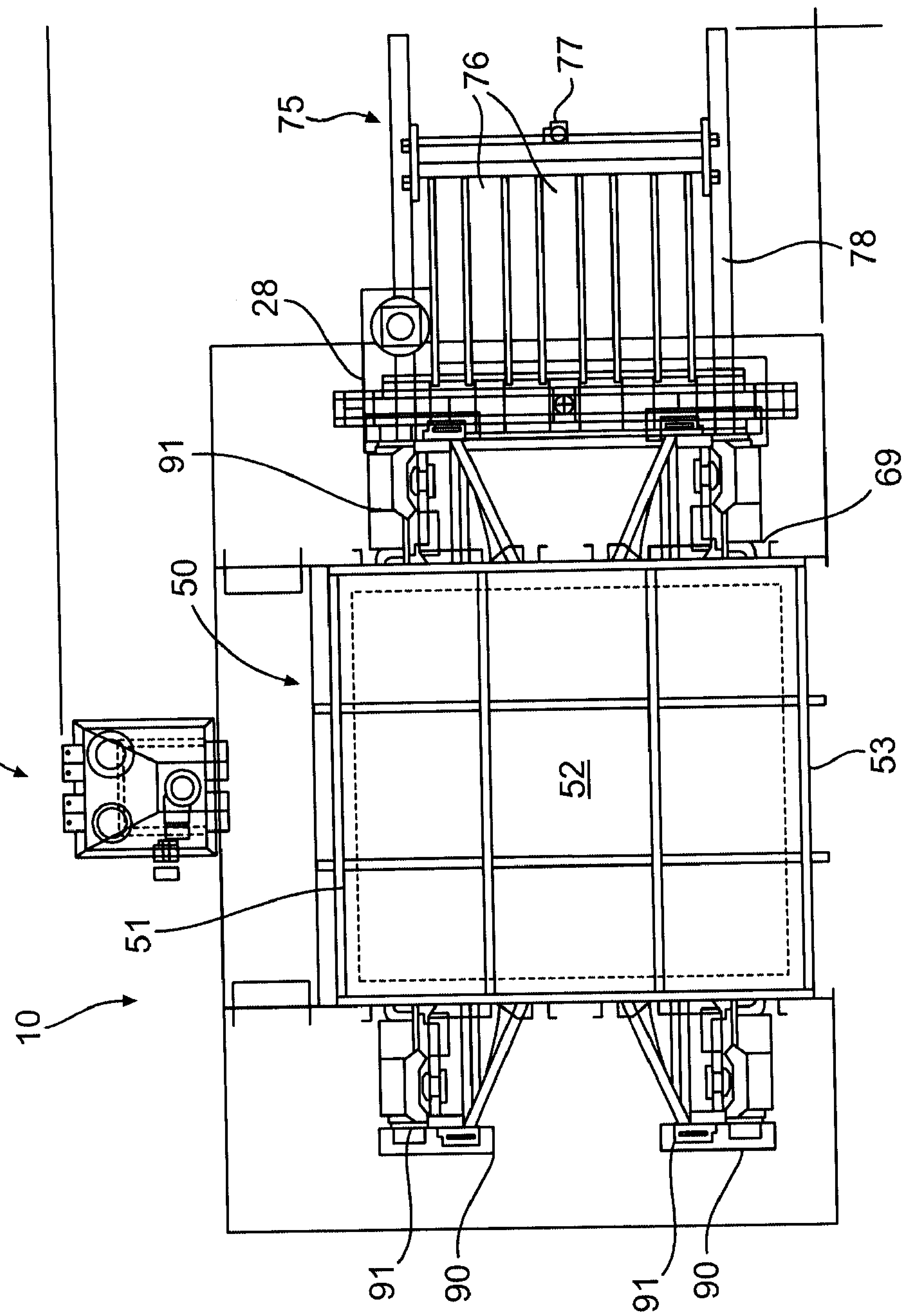

FIG. 6A

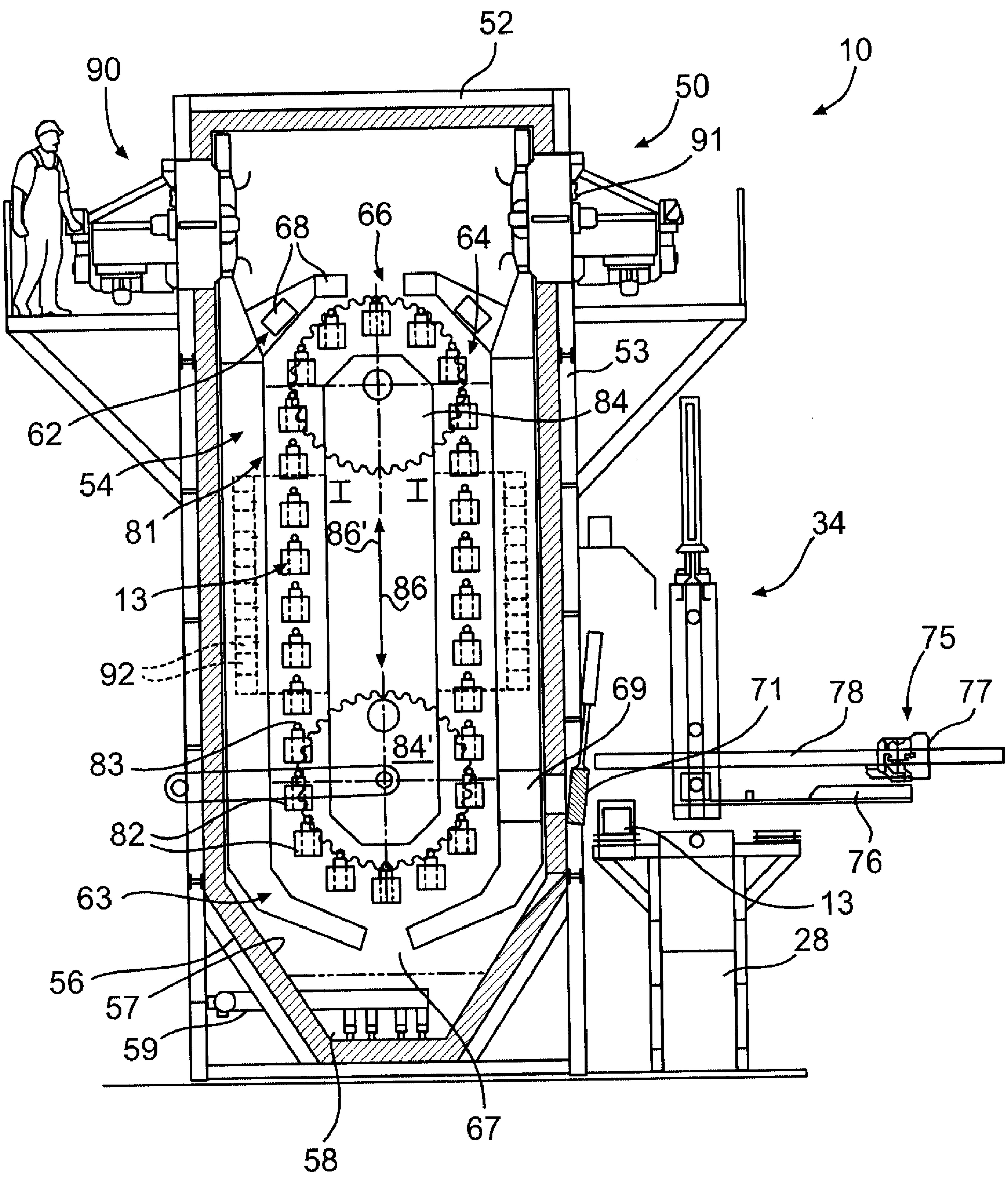
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FIG. 6B

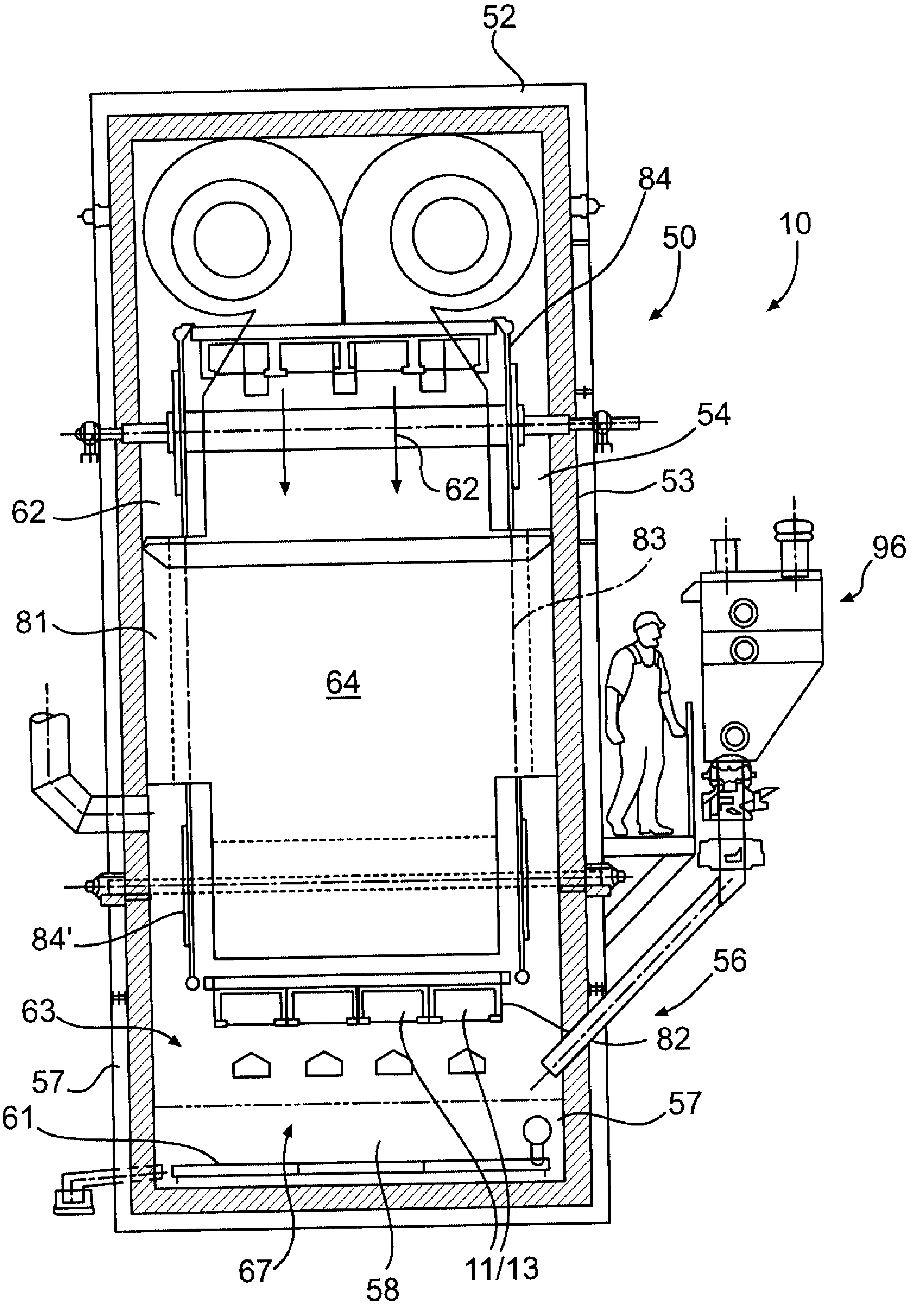


FIG. 6C

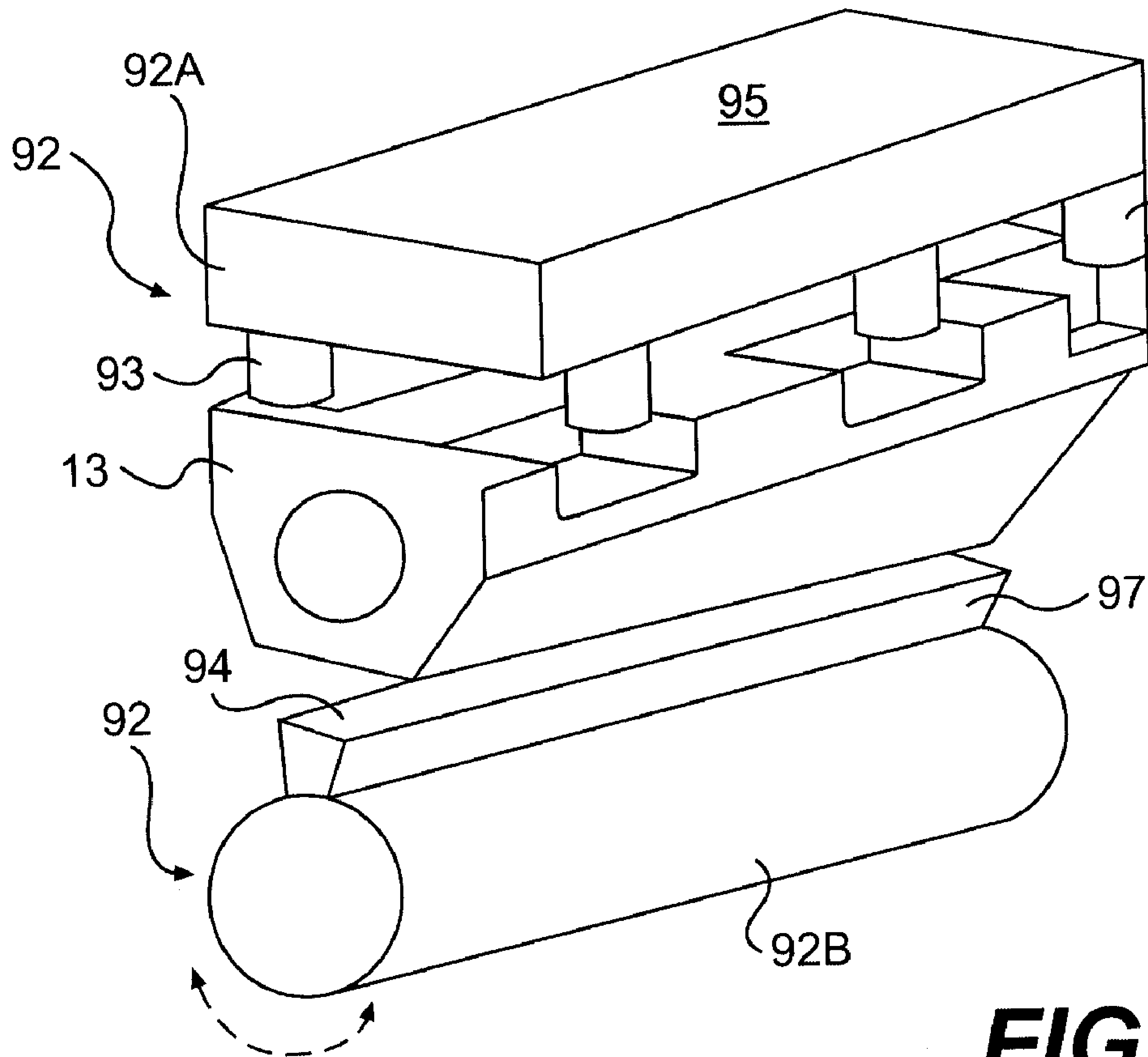


FIG. 7A

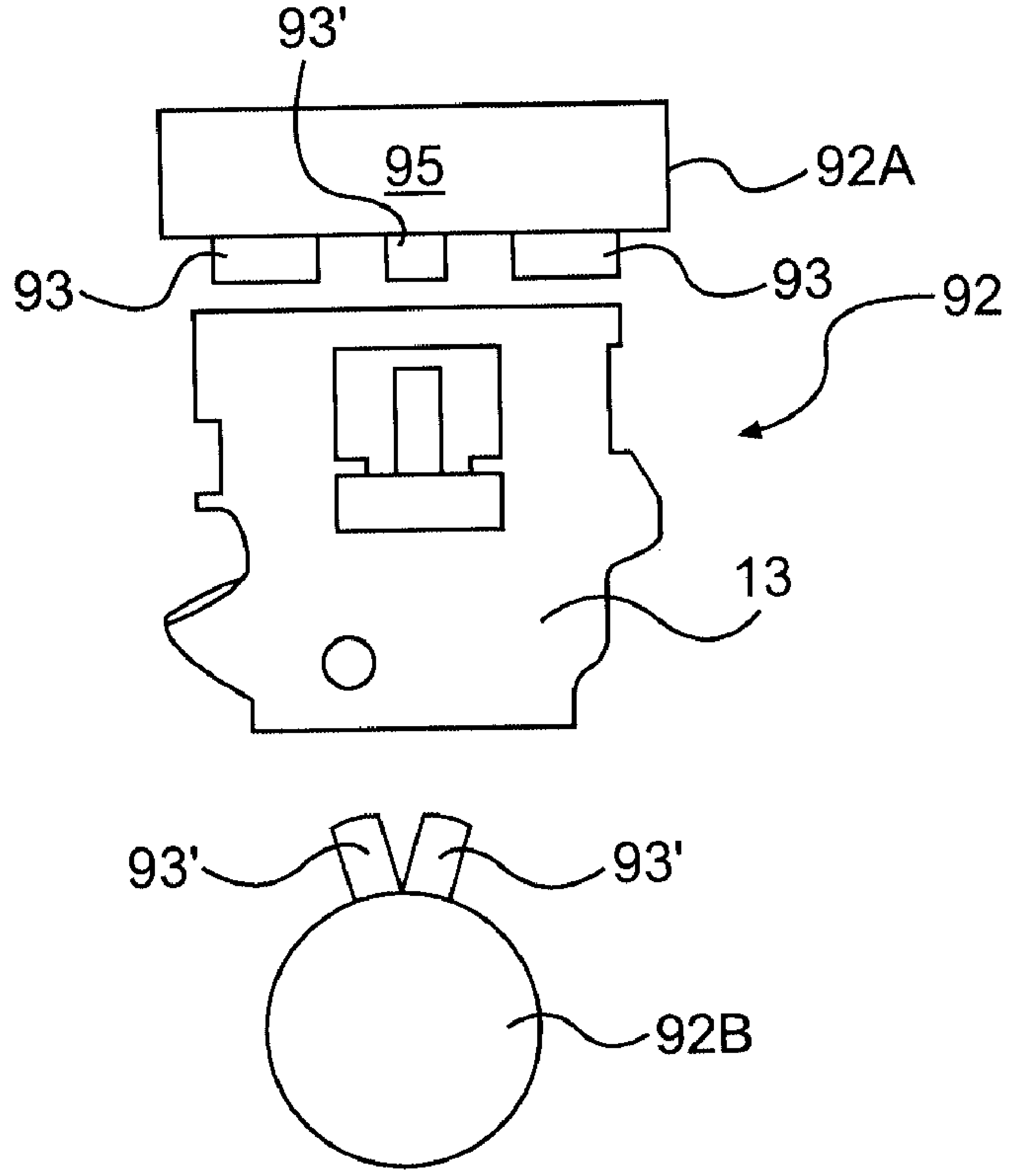


FIG. 7C

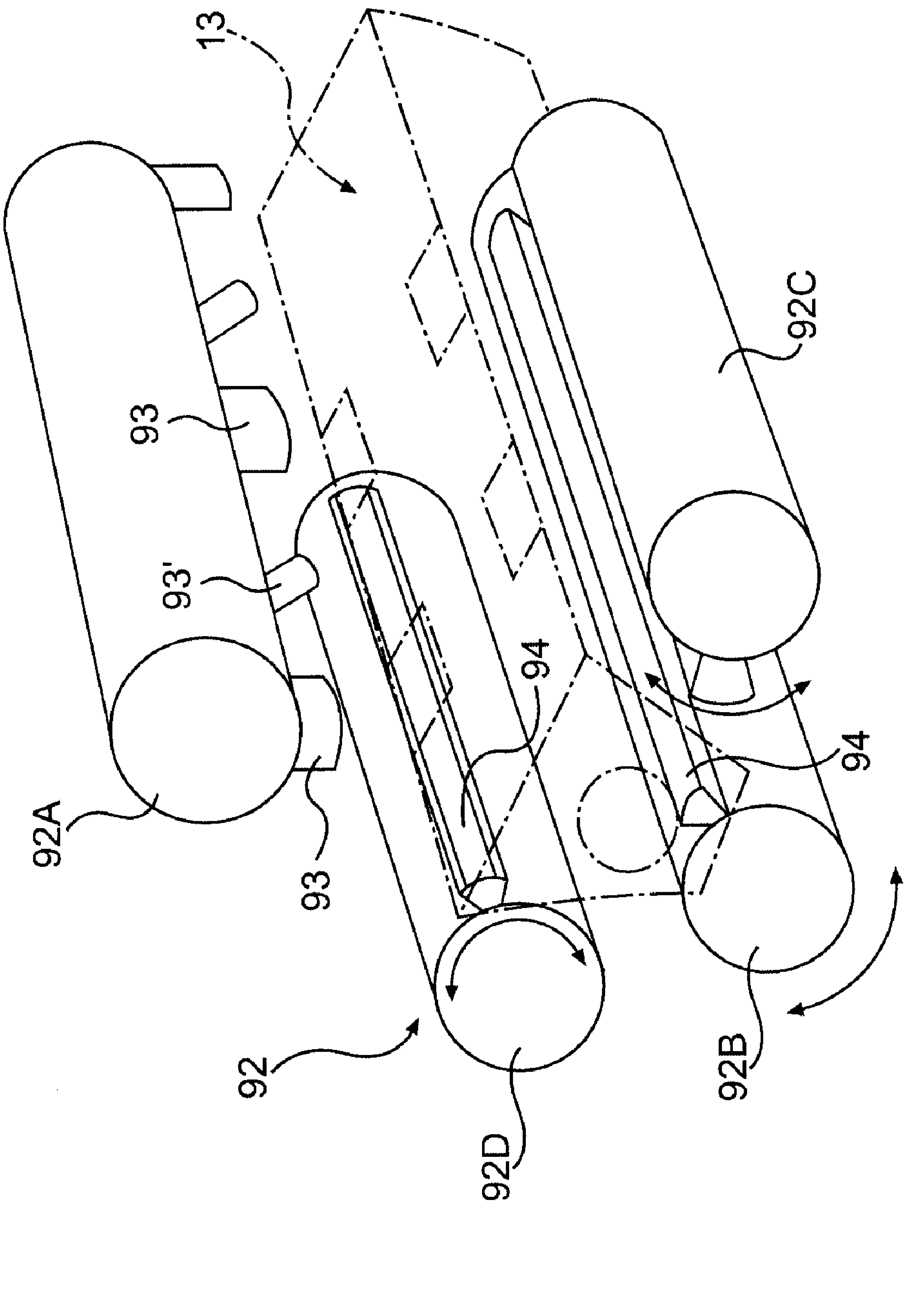


FIG. 7B

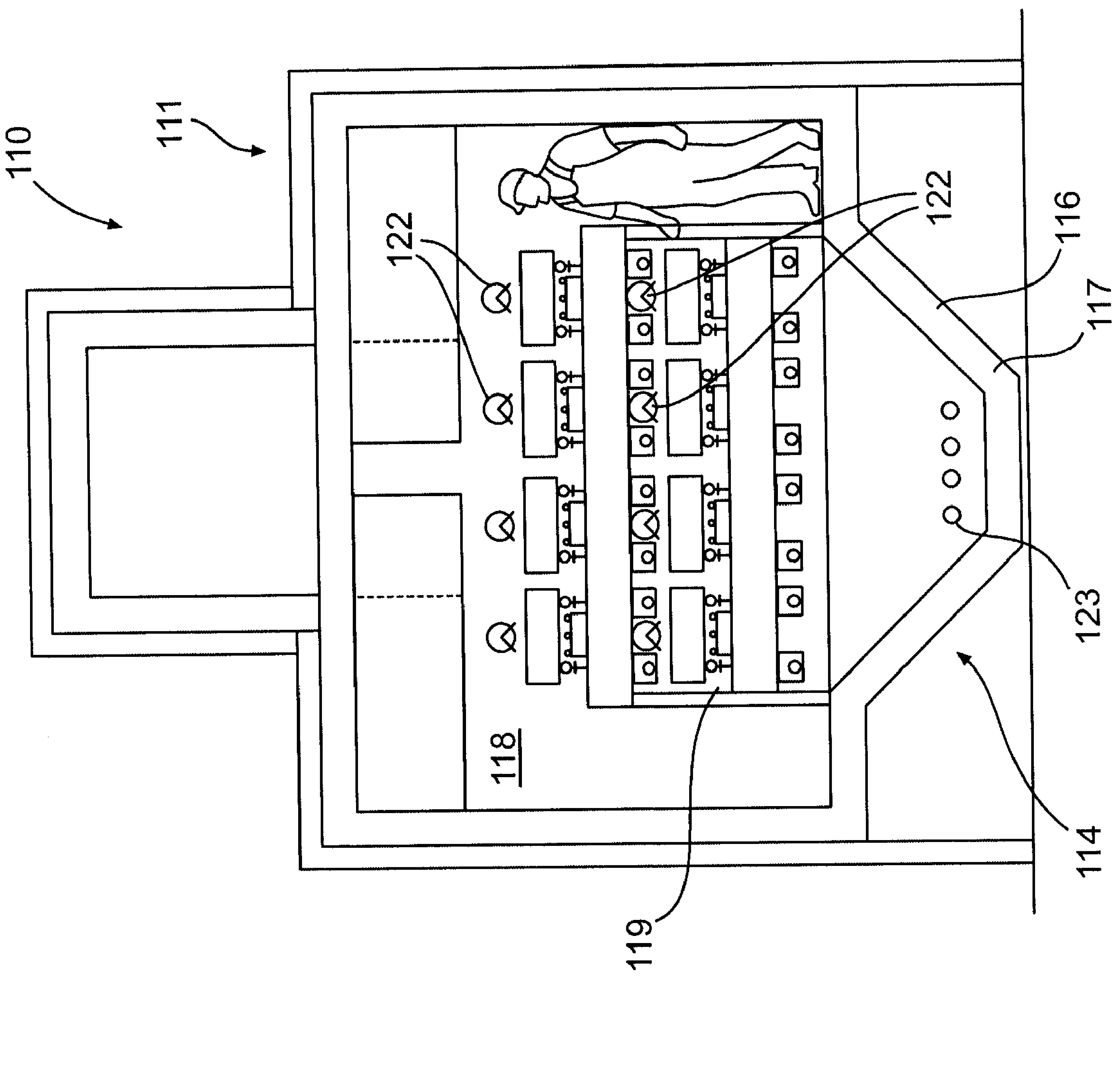
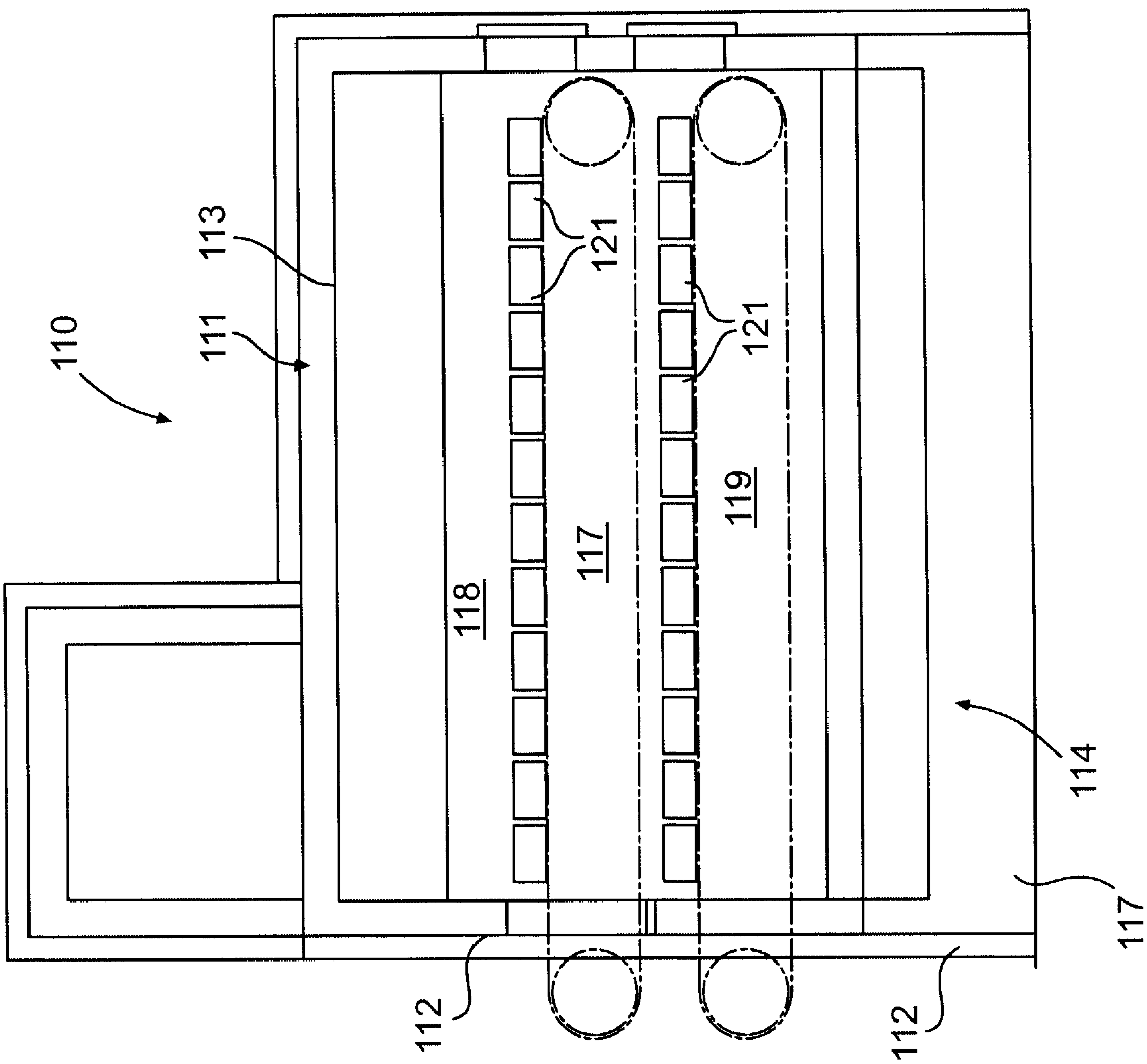


FIG. 8A

FIG. 8B



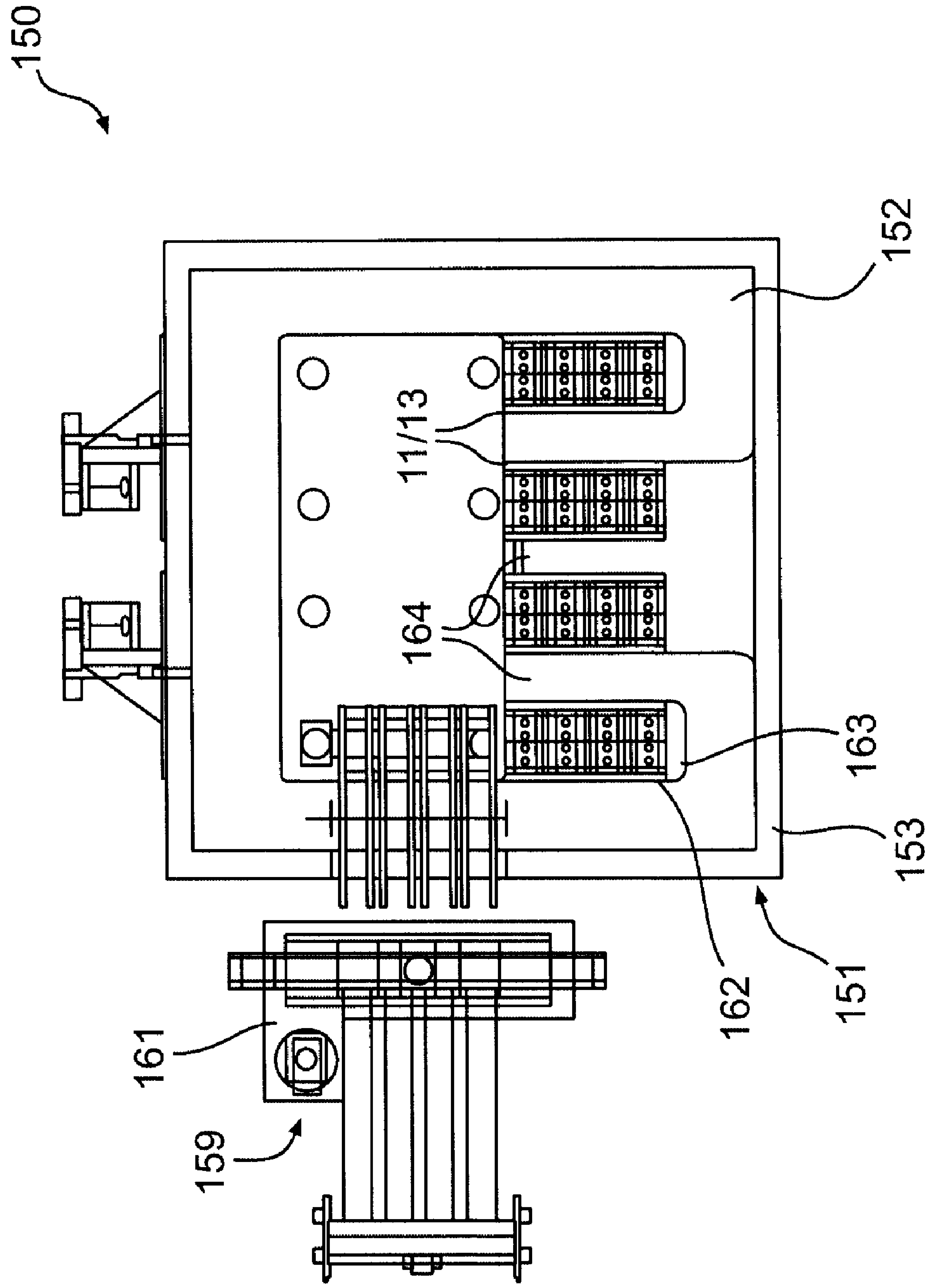


FIG. 9A

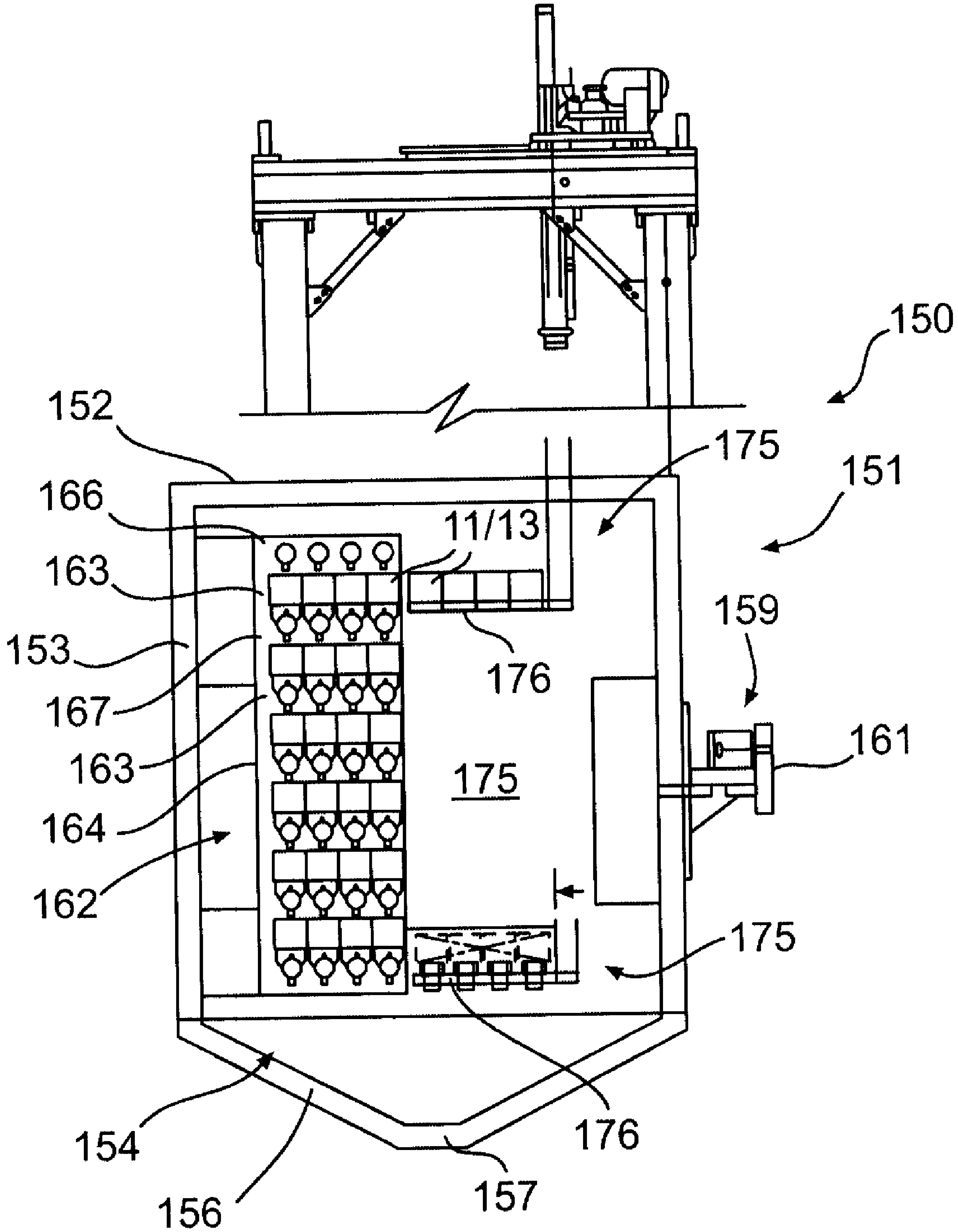

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FIG. 9B

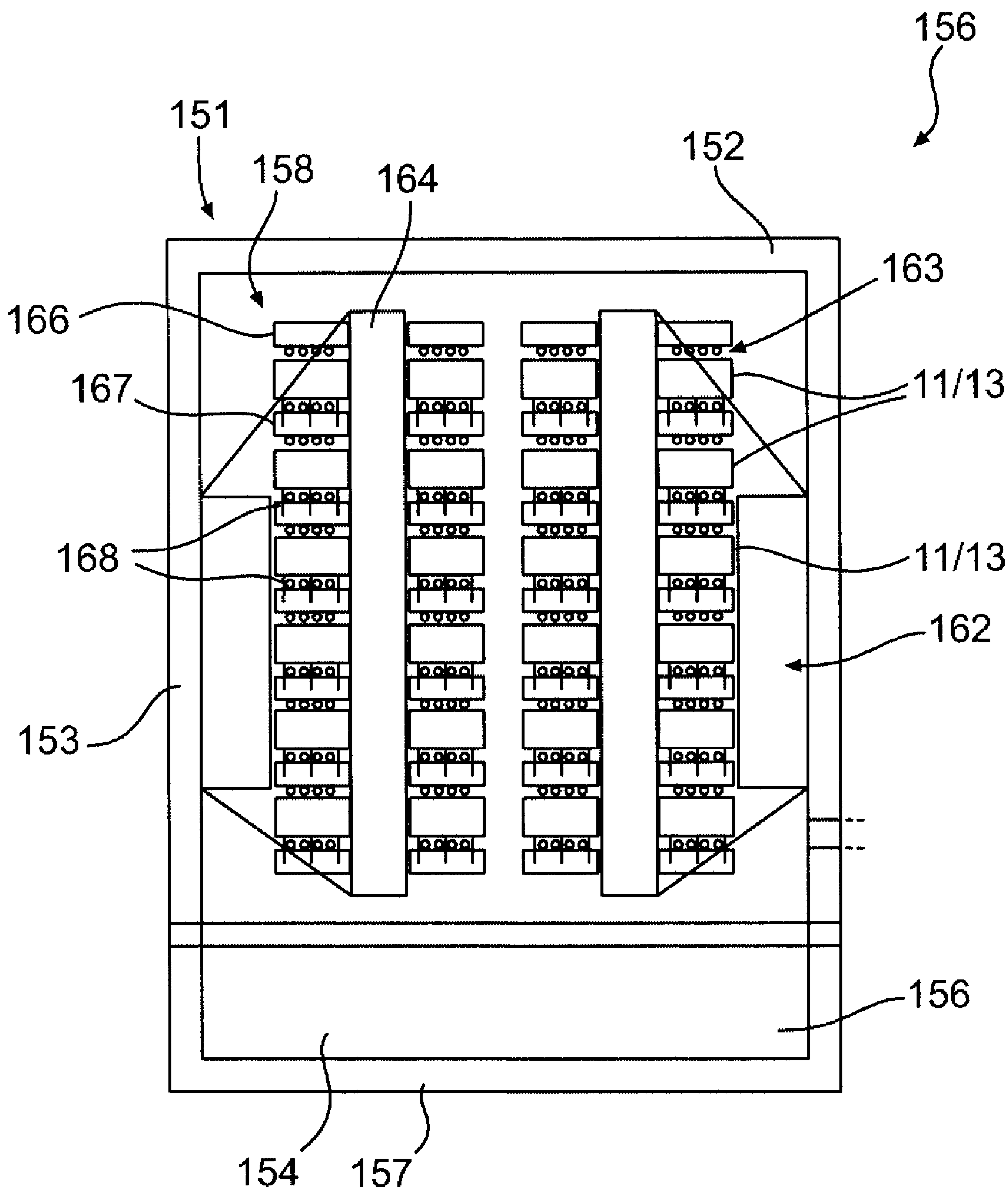
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FIG. 9C

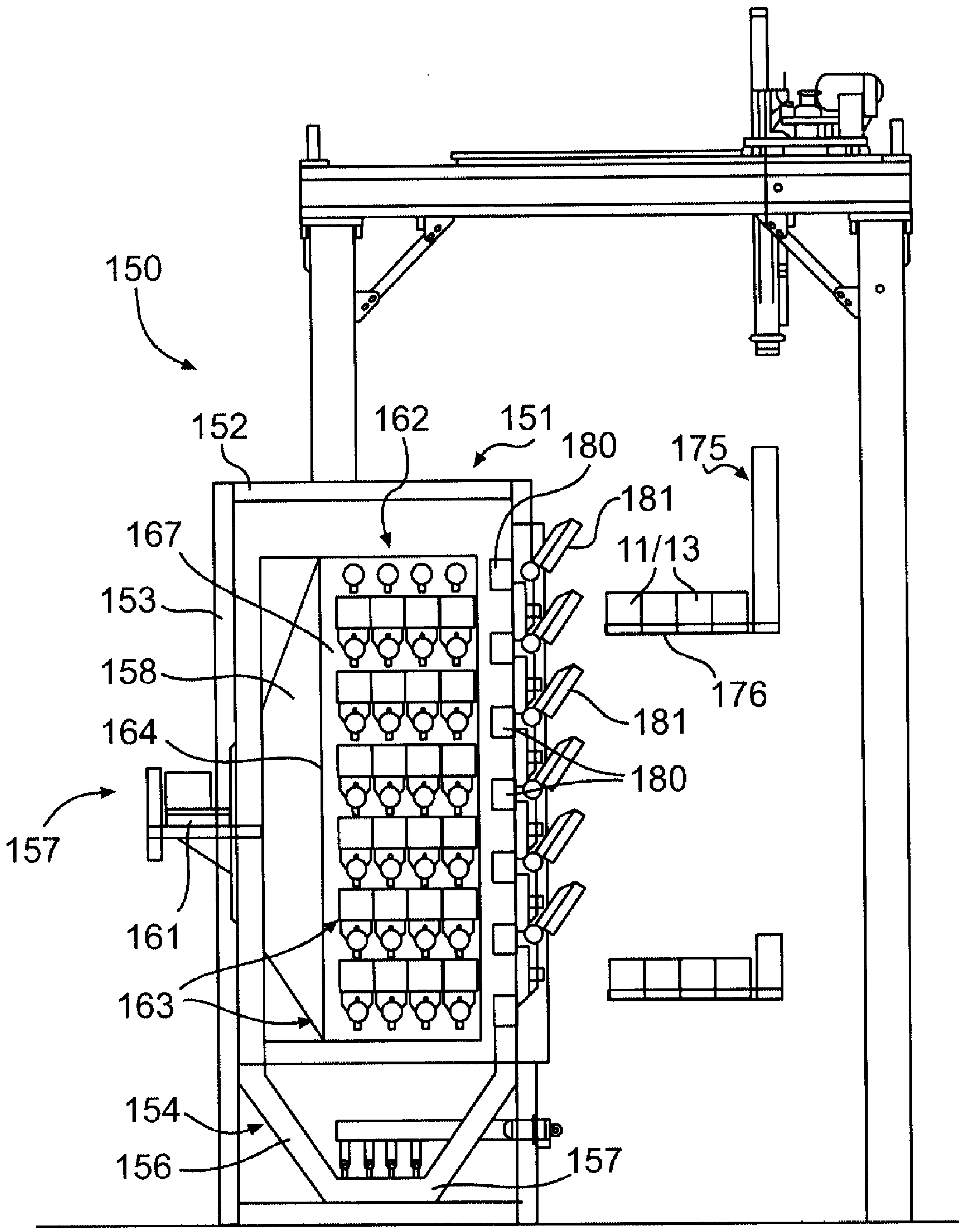
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FIG. 9D

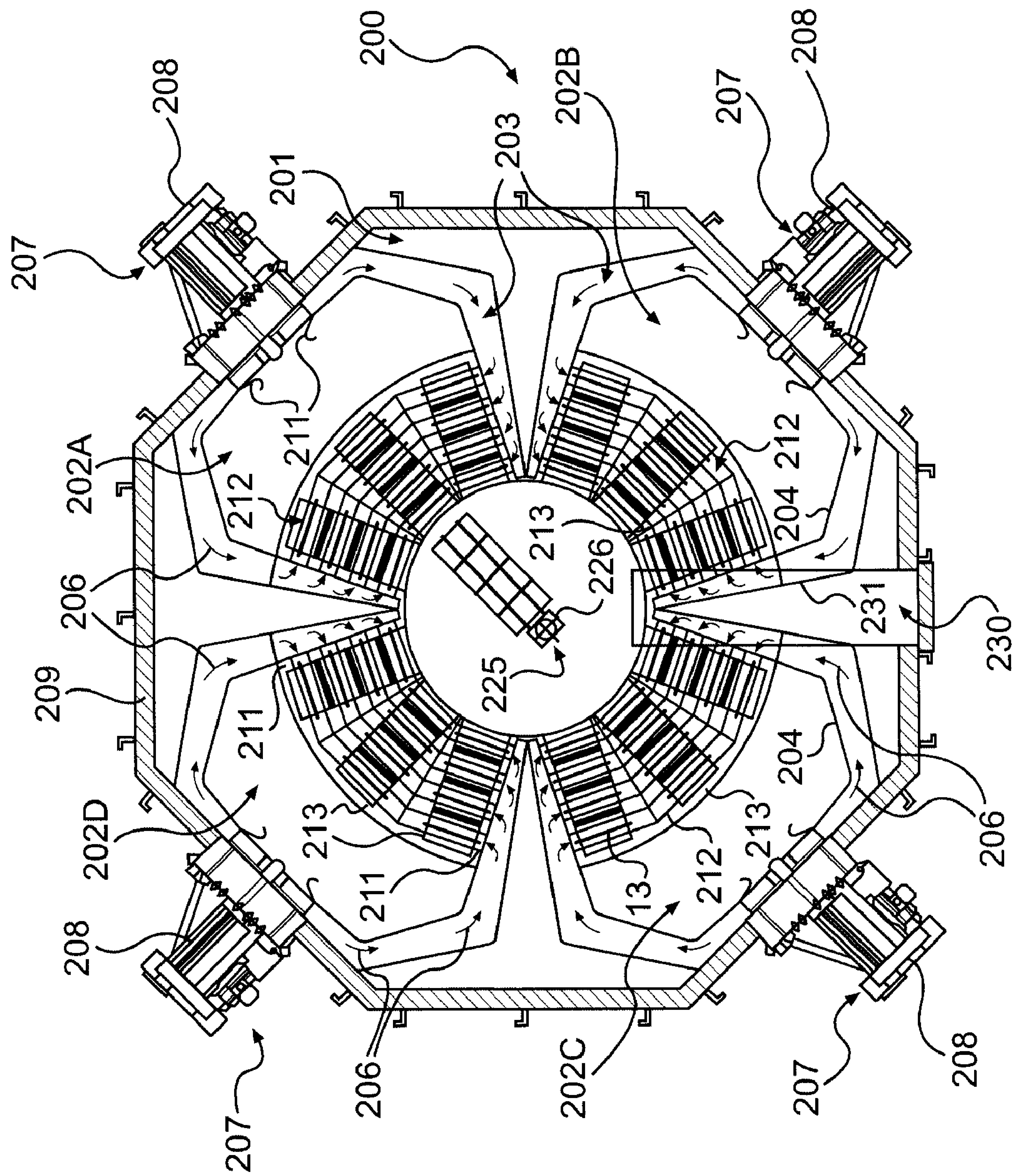
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FIG. 10A

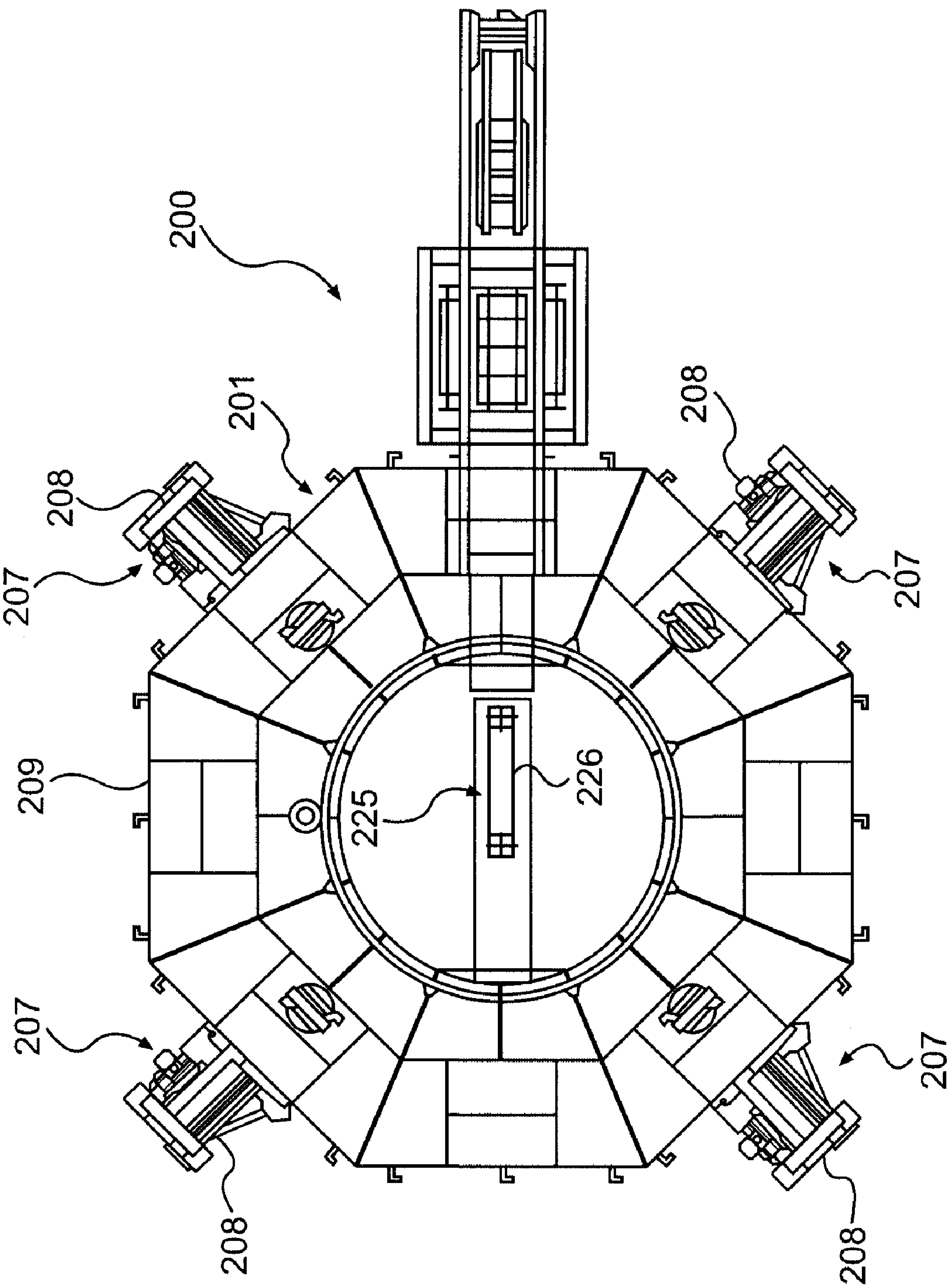

FIG. 10B

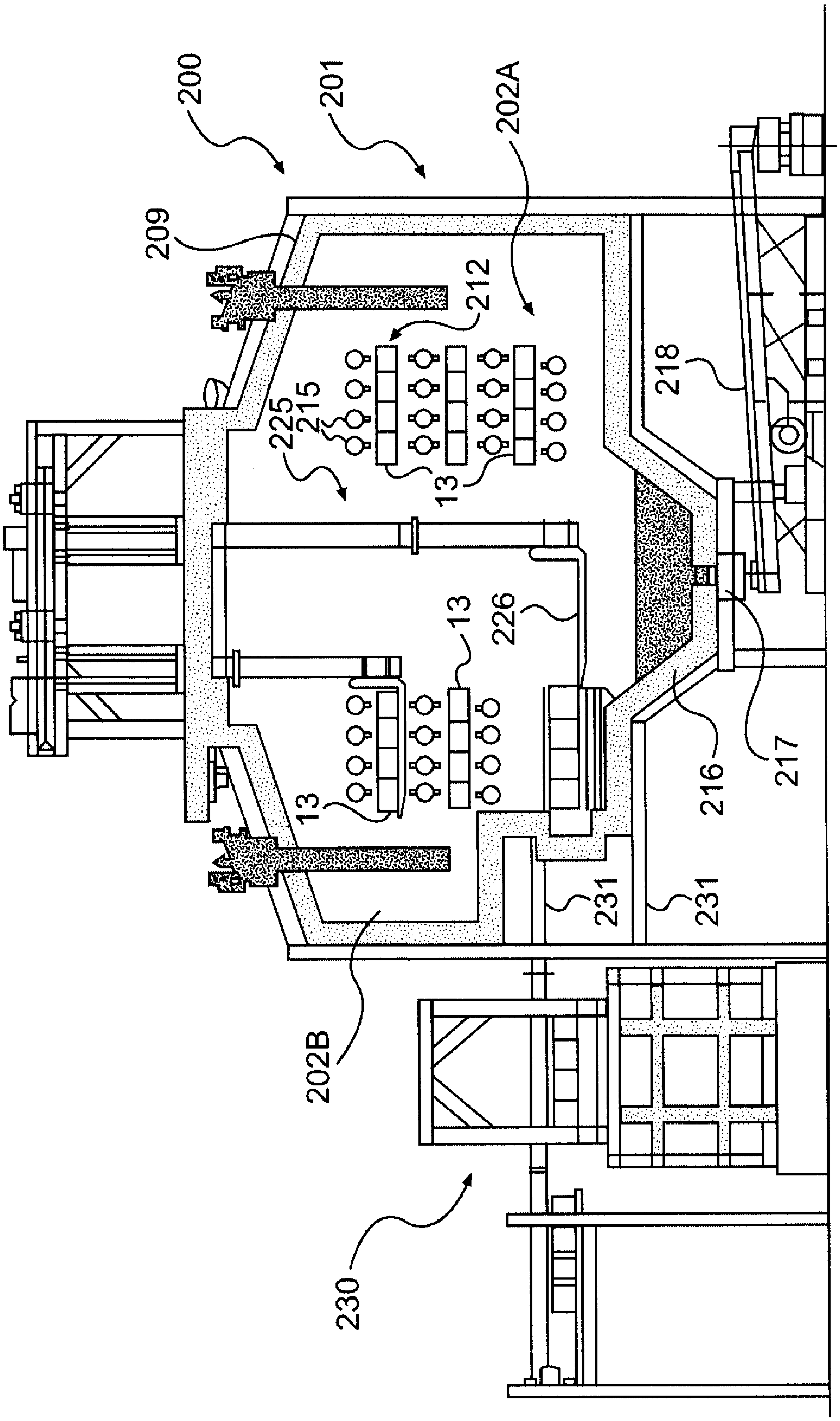
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FIG. 11A

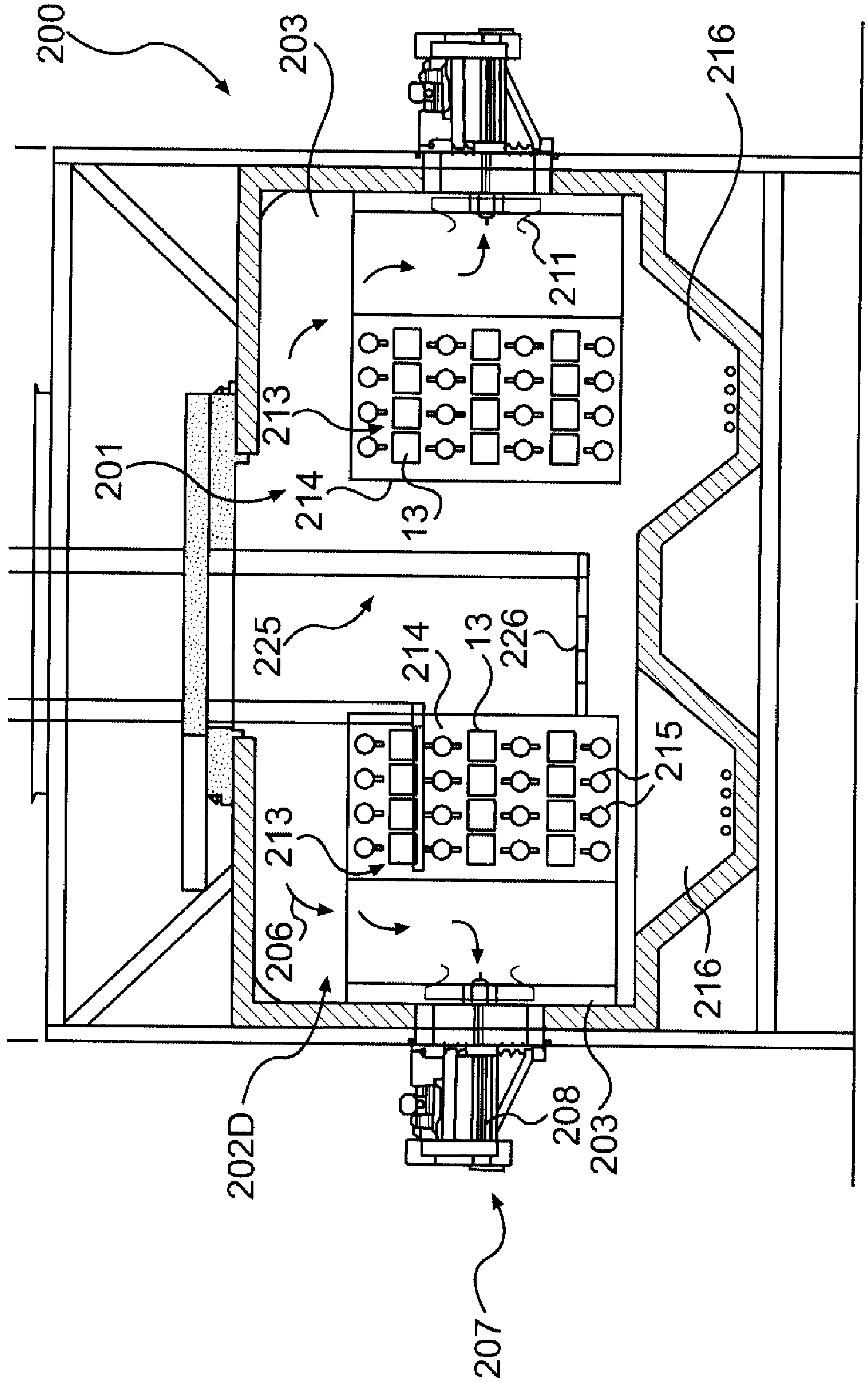
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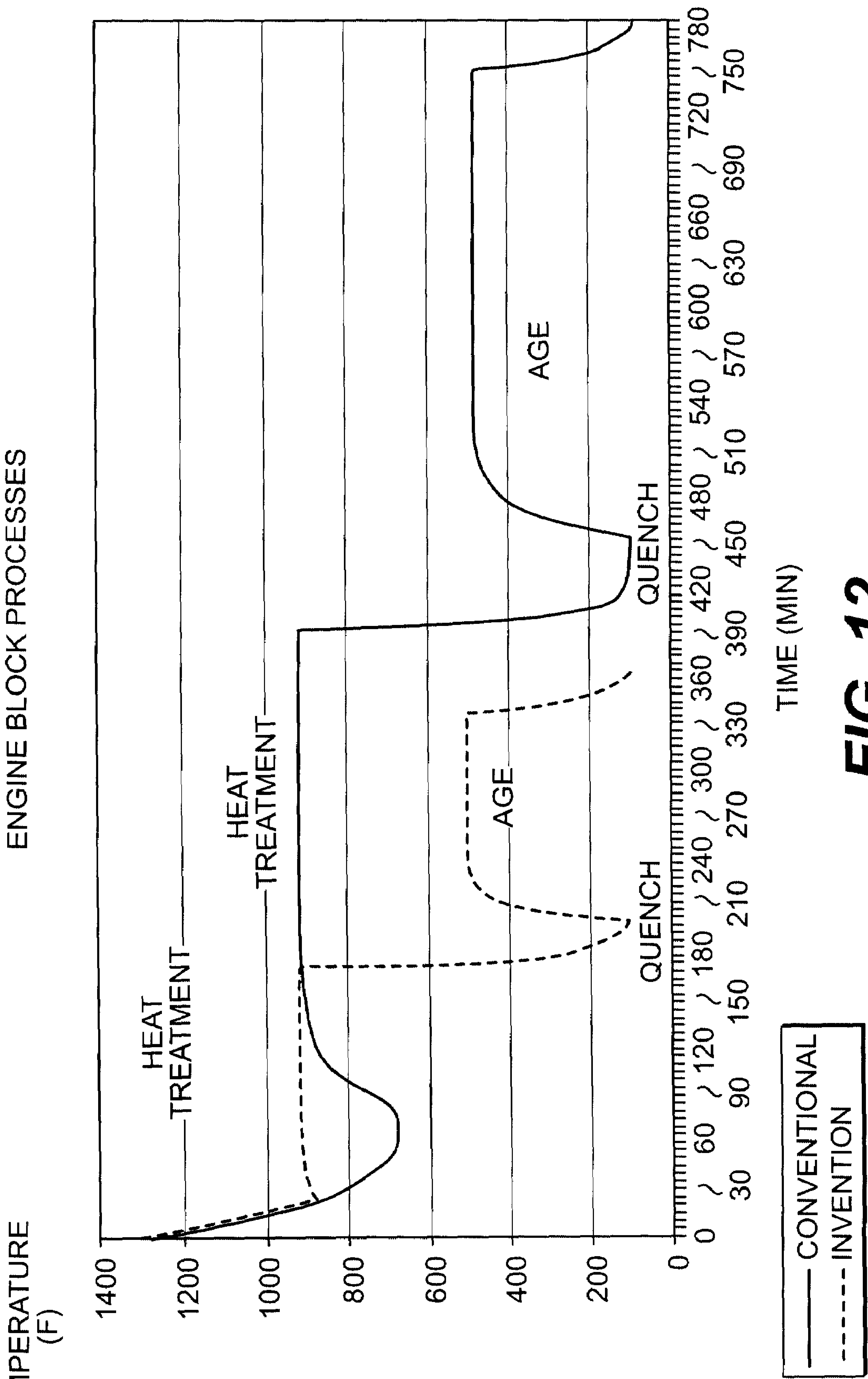
FIG. 11B


ENGINE BLOCK PROCESSES
TEMPERATURE (F)
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800
600
400
200
0
HEAT TREATMENT
HEAT TREATMENT
QUENCH
AGE
QUENCH
AGE
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360
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450
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570
600
630
660
690
720
750
780
TIME (MIN)
CONVENTIONAL
INVENTION

FIG. 12

VERTICAL HEAT TREATMENT SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present patent application claims the benefit of the filing date of U.S. provisional patent application No. 60/908,743, filed Mar. 29, 2007 and U.S. provisional patent application No. 60/909,048, filed Mar. 30, 2007, according to the statutes and rules governing provisional patent applications, particularly USC §119(e)(1) and 37 CFR §1.78(a)(4) and (a)(5). The specification and drawings of the provisional patent application are specifically incorporated fully herein by reference.

BACKGROUND OF THE INVENTION

[0002] Traditionally, in conventional processes for forming metal castings, a mold, such as a metal die or sand mold having an interior chamber with the exterior features of a desired casting defined therein, is filled with a molten metal. A sand core that defines interior features of the castings is received and/or positioned within the mold to form the interior detail of the casting as the molten metal solidifies about the core. After the molten metal of the castings has solidified, the castings generally are moved to a treatment furnace(s) for heat treatment of the castings, removal of sand from the sand cores and/or molds, and other processing as required. The heat treatment processes condition the metal or metal alloys of the castings to achieve the desired physical characteristics for a given application.

[0003] FIG. **1**A illustrates one type of a conventional heat treatment apparatus in which a series of castings can be placed within a basket and passed along a roller health or similar conveying mechanism through one or more heating chambers of the heat treatment apparatus. As the castings are passed through the chambers of the heat treatment apparatus, the castings are heated to a solution heat treatment temperature. Additionally, as the castings move along the chambers of the heat treating furnace, the sand cores or molds of the castings also can be broken down as their binder materials are combusted, such that the castings can be de-cored and their molds broken down and removed, with the sand falling beneath the roller hearth for collection. After the castings have been heat treated, they can be removed from the heat treatment unit or furnace and directed to a quench station or tank.

[0004] During the transfer of the castings from the pouring station to the heat treatment station, and especially if the castings are allowed to sit for any appreciable amount of time, however, the castings may be exposed to the ambient environment of the foundry or metal processing facility. As a result, the castings tend to rapidly cool down from a molten or semi-molten temperature. While some cooling of the castings is necessary to allow the castings to solidify, the more the temperature of the castings drops, and the longer the castings remain below a process critical temperature (also referred to herein as the "process control temperature") of the castings, the more time is required to heat the castings up to a desired heat treatment temperature and to heat treat the castings. For example, as illustrated in FIG. **1**B, it has been found that for certain types of metals, for every minute of time that the castings drops below its process control temperature, at least about four minutes or more of extra heat treatment time will be required to achieve the desired solution heat treatment results in the castings. Thus, even dropping below the process control temperature for the metal of the castings for as few as 10 minutes may require at least about 40 minutes of additional heat treatment time to achieve the desired physical properties. As a consequence, therefore, castings typically are heat treated for 2 to 6 hours, in some cases longer, to ensure the desired heat treatment effects are achieved in all the castings of a batch or series. This results in greater utilization of energy and, therefore, greater heat treatment costs.

[0005] Accordingly, it can be seen that a need exists for a system and method of heat treating castings that addresses the foregoing and other related and unrelated problems in the art.

SUMMARY OF THE INVENTION

[0006] Briefly described, the present invention generally comprises a system for enabling the pouring, forming, heat treating, and further processing of castings formed from metal and/or metal alloys at enhanced rates and efficiency. The castings are formed at a pouring station at which a molten metal such as aluminum, iron, or a metal alloy, is poured into a mold or die, such as a permanent metal mold, semi permanent mold, or a sand mold. The molds then are moved from the pouring or casting position to a transfer position, where the castings can be removed from their molds or transferred directly to a vertical heat treatment unit according to the present invention. The transfer mechanism typically includes a robotic arm, crane, overhead hoist or lift, pusher, conveyor, or similar conveying mechanism. The same mechanism also may be used to remove the castings from their molds and to transfer the castings to the vertical heat treatment unit(s). During this transition from the pouring station to the vertical heat treatment unit(s), the molten metal of the castings generally is permitted to cool to an extent sufficient to form the castings, while generally being monitored and heat applied thereto as needed to maintain the castings at or above a process control temperature for the metal thereof.

[0007] The vertical heat treatment unit according to the present invention comprises a vertically aligned heat treatment or "cell unit" having a reduced footprint such that it typically can be arranged adjacent or in close proximity to a loading carousel for one or more pouring stations, which carousels can be positioned adjacent their associated pouring stations. The castings also can he received on a transfer line or monorail from their pouring stations and then transferred directly to a vertical heat treatment unit or to a loading carrousel for each vertical heat treatment unit. Each vertical heat treatment unit or cell unit generally can include a vertically extending furnace chamber having heat sources, such as blowers, fans, radiant heaters, infrared, inductive, convection, conductive, or other types of heating elements. The ceiling and walls of the furnace chamber further generally will include a radiant material that radiates or directs heat toward the castings and/or molds with the castings therein, as they are moved through the furnace chamber. The castings are received and maintained within their cell unit or vertical heat treatment system for a time and at temperatures sufficient to heat treat the castings as needed to achieve desired mechanical properties thereof.

[0008] The heat sources further can include a variety of heating systems including conduction, convection, and other sources. In one embodiment, the heat sources can comprise high velocity forced air heating sources that direct turbulent, high velocity flows of heated air or other fluid media at velocities flows of approximately 2,500-4,000, up to approximately 40,000 feet per minute generally at distances of about 21-26 inches or less, and as short as 2-10 inches, from the castings. The velocity of the heated air flows and the distance of the applicator nozzles from the castings and their molds generally can be determined based upon the diameter and the configuration(s) of the nozzles being used (i.e., use of a series of spaced large, medium, or small diameter circular nozzles, slotted nozzles, or other configurations) and the positions/locations of the nozzles with respect to the centerlines of the castings as they are conveyed through the furnace chamber of the vertical heat treatment unit, which can be adjusted depending on sizes of the castings and the volume and velocity of the flames. The air flows further generally are at temperatures sufficient to promote heat treatment of the castings and additionally can assist with mold breakdown and core removal as the castings are moved through their vertical heat treatment units.

[0009] The vertical heat treatment unit further can include a conveying mechanism such as a rotary carousel that extends upwardly through the furnace chamber and includes a series of platforms, trays or racks on which a series of castings, i.e., 1-4 or more castings, are received. The castings typically will remain within in their molds, although they also can be previously removed from their molds prior to introduction into the vertical heat treatment unit. The castings generally will be fed into the furnace chamber by a manipulator, which can include a crane, forklift, or similar mechanism or can comprise the transfer robot of an associated loading carousel. As the castings are fed into the furnace chamber, the rotary carousel generally is operated in a up and down stepping motion, for example moving up one step to receive the castings and then downwardly two steps so as to ensure that a desired separation between incoming (colder) castings and outgoing (fully heated) castings is as large as possible. The vertical heat treatment unit can further include features that assist in removal and reclamation of the sand from the molds of the castings, which generally will be collected and reclaimed for reuse.

[0010] Alternatively, the castings can be received within the vertical heat treatment unit on a gantry or elevator type conveying mechanism and placed within one or more compartments or chambers of a grid unit for heat treatment. Each of the compartments are insulated along their side walls as to prevent heat transfer between castings through the side walls, while the floors and ceilings thereof can have slots or openings to enable sand removed from the sand cores and/or molds of the castings to pass therethrough for collection at the bottom of the vertical heat treatment unit. In another alternative embodiment, the vertical heat treatment unit can include a series of conveyors in a vertically stacked arrangement with heat sources such as high velocity fluid media nozzles mounted therealong for directing heated fluid flows toward the castings.

[0011] The vertical heat treatment unit of the present invention thus provides a significantly smaller footprint within the casting facility, which enables the vertical heat treatment unit to be placed in as close proximity as possible to the pouring stations. The vertical heat treatment unit of the present invention additionally can utilize existing robotic transfer mechanisms, lifts, or cranes for receiving the castings substantially directly from the pouring stations or from a loading carousel, with the time that the castings are exposed to the ambient environment of the metal processing facility thus being substantially minimized. As a result, the castings can be maintained at or above their process control temperature, as they are transferred from the pouring station to the vertical heat treatment unit of the present invention. In addition, the castings further can be monitored as they are removed from their pouring stations and transfered to their vertical heat treatment units, and additional heat added, such as by additional heating sources such as infrared lamps, heated fluid flows, inductive heaters, and/or other heat sources, as needed to substantially arrest cooling and/or maintain the temperature of the castings substantially at or above the process control temperature for the metal of the castings. Accordingly, the time required to heat treat the castings can be significantly reduced from approximately 2-6 hours down to as low as about 40 minutes to an hour.

[0012] Various objects, features and advantages of the present invention will become apparent to those skilled in the art upon review of the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. **1**A is a schematic illustration of an exemplary conventional heat treatment unit.

[0014] FIG. **1**B is a graphical representation of a heat treatment cycle, illustrating the increase in heat treatment time required for each minute of time the temperature of the casting is below its process control temperature.

[0015] FIG. **2**A is a schematic illustration of an exemplary metal casting processing system according to various aspects of the present invention.

[0016] FIG. **2**B is a schematic illustration of another exemplary metal casting processing system illustrating the collection and transfer of castings from multiple pouring stations to vertical heat treatment units according to various aspects of the present invention.

[0017] FIG. **3** is a perspective view of a casting and mold.

[0018] FIG. **4** is a perspective illustration of the vertical heat treatment according to one embodiment of the vertical heat treatment unit of the present invention.

[0019] FIGS. **5**A and **5**B are perspective views of the vertical heat treatment unit of FIG. **4**, with parts broken away to illustrate the internal portions of the unit.

[0020] FIGS. **6**A is a top plan view of the vertical heat treatment unit of FIG. **4**.

[0021] FIG. **6**B is a cross-sectional view of the vertical heat treatment unit of FIG. **4** illustrating the operation of the carousel.

[0022] FIG. **6**C is a side elevational view of the vertical heat treatment unit of FIG. **4** illustrating the forced air flow therethrough.

[0023] FIGS. **7**A-**7**C are perspective views of example embodiments of nozzle configurations for use in the vertical heat treatment units.

[0024] FIGS. **8**A and **8**B are side elevational views of yet another embodiment of the vertical heat treatment unit of the present invention in which the castings are conveyed along stacked, laterally extending conveyor mechanisms.

[0025] FIG. **9**A is a top plan view of yet another embodiment of a vertical heat treatment unit according to the principles of the present invention.

[0026] FIG. **9**B is a side elevational view, with parts broken away, of the embodiment of the vertical heat treatment unit of FIG. **9**A.

[0027] FIG. 9C is a side elevational view of the embodiment of the vertical heat treatment unit of FIG. 9A, taken in cross section along lines B-B of FIG. 9A.

[0028] FIG. 9D is a side elevational view schematically illustrating an alternative embodiment of the loader of the vertical heat treatment unit of FIGS. 9A-9B.

[0029] FIG. 10A-10B are top plan views of a further embodiment of a vertical heat treatment unit according to the principles of the present invention.

[0030] FIGS. 11A-11B are side elevational views illustrating the vertical heat treatment unit of FIGS. 10A-10B.

[0031] FIG. 12 is a graphical comparison of the processing of a casting utilizing a conventional heat treatment process and system versus the system and process of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0032] Referring now in greater detail to the drawings in which like numerals refer to like parts throughout the several views, FIGS. 2A-2B schematically illustrates an exemplary integrated metal processing facility or system 5 including the vertical heat treatment unit or "cell unit" 10 according to the present invention for processing metallurgical castings. Metal casting processes generally are known to those skilled in the art and a traditional casting process will be described only briefly for reference purposes. It will be understood by those skilled in the art that the present invention can be used in any type of casting process, including metal casting processes for forming aluminum, iron, steel, and/or other types of metal and metal alloy castings. The present invention thus is not and should not be limited solely for use with a particular casting process or a particular type or types of metals or metal alloys.

[0033] As illustrated in FIG. 2A, a molten metal or metallic alloy M typically is poured into a die or mold 11 at a pouring or casting station 12 for forming a casting 13, such as a cylinder head, engine block, or similar cast part as illustrated in FIG. 3. A casting core 14 formed from sand and binder, such as a phenolic resin or other known binder materials, can be received or placed within the mold 11 to create hollow cavities and/or casting details or core prints within the casting. Each of the molds alternatively can be a permanent mold or die, typically formed from a metal such as steel, cast iron, or other material as is known in the art. Such molds may have a clam-shell style design for ease of opening and removal of the casting therefrom. Alternatively still, the molds can be "precision sand mold" type molds and/or "green sand molds", which generally are formed from a sand material such as silica sand or zircon sand mixed with a binder such as a phenolic resin or other binder as is known in the art, similar to the sand casting cores 14. The molds further may be semi-permanent sand molds, which typically have an outer mold wall formed form sand and a binder material, a metal such as steel, or a combination of both types of material.

[0034] Additionally, the molds may be provided with one or more user openings (not shown) to serve as reservoirs for molten metal. These reservoirs supply extra metal to fill the voids formed by shrinkage as the metal cools and passes from the liquid to the solid state. When the cast article is removed from its mold, the solidified metal in the opening remains attached to the casting as a projection or "riser" (not shown). These risers generally are non-functional and are subsequently removed, typically by mechanical means.

[0035] It will be understood that the term "mold" will be used hereafter to refer generally to all types of molds, including, without limitation, those discussed above, including permanent or metal dies, semi-permanent and precision sand mold types, and other metal casting molds, except where a particular type mold is indicated. It further will be understood that in the various embodiments discussed below, unless a particular type of mold and/or heat treatment process is indicated, the present invention can be used for heat treating castings that have been removed from their permanent molds, or that remain within a sand mold for the combined heat treatment and sand mold break-down, removal, and sand reclamation.

[0036] A heating source or element, such as a heated air blower, gas-fired heater mechanism, electric heater mechanism, fluidized bed, or any combination thereof also may be provided adjacent the pouring station for preheating the molds. Typically, the molds are preheated to a desired temperature depending upon the metal or alloy used to form the castings. For example, for aluminum, the mold may be preheated to a temperature of from about 400° C. to about 600° C. The varying preheating temperatures required for preheating the various metallic alloys and other metals for forming castings are well known to those skilled in the art and can include a wide range of temperatures above and below from about 400° C. to about 600° C. Additionally, some mold types require lower process temperatures to prevent mold deterioration during pouring and solidification. In such cases, and where the metal process temperature should be higher, a suitable metal temperature control method, such as induction heating, may be employed.

[0037] Alternatively, the molds may be provided with internal heating sources or elements for heating the molds. For example, where a casting is formed in a permanent type metal die, the die may include one or more cavities or passages formed adjacent the casting and in which a heated medium such as a thermal oil or other fluid material is received and/or circulated through the dies for heating the dies. Thereafter, thermal oils or other suitable media may be introduced or circulated through the die, with the oil being of a lower temperature, for example, from about 250° C. to about 300° C., to cool the casting and cause the casting to solidify. A high temperature thermal oil, for example, heated to from about 500° C. to about 550° C., then may be introduced and/or circulated through the die to arrest cooling and raise the temperature of the casting back to a soak temperature for heat treating. The pre-heating of the die and/or introduction of heated media into the die may be used to initiate heat treatment of the casting. Further, preheating helps maintain the metal of the casting at or near a heat treatment temperature to minimize heat loss as the molten metal is poured into the die, solidified, and transferred to a subsequent processing station for heat treatment. If additionally desired, the casting also may be moved through a radiant chamber or zone to prevent or minimize cooling of the casting.

[0038] As shown in FIG. 3, each of the molds 11 generally includes side walls 16, an upper wall or top 17, a lower wall or bottom 18, which collectively define an internal cavity 19 in which the molten metal is received and formed into the casting 13. A pour opening 21 generally is formed in the upper wall or top 17 of each mold and communicates with an internal cavity for passage 22 of the molten metal through each mold and into its internal cavity 19 at the pouring station. As indicated in FIG. 2A, the pouring station 12 generally includes a ladle or similar mechanism **23** for pouring the molten metal M into the molds **11**. The pouring station **12** further can include a conveyor, carousel, or similar conveying mechanism, that moves one or more molds from a pouring or casting position, indicated by **24** in FIG. **2**A, where the molten metal is poured into the molds, to a transfer point or position **26** (FIG. **2**B), at which the castings can be removed from their molds or transferred while remaining in their molds from the pouring station to the vertical heat treatment unit **10** for heat treatment. Prior to and/or during such transfer, the molten metal is allowed to cool to a desired extent or temperature within the molds as needed for the metal to sufficiently solidify into the castings. The castings then are heat treated at a desired heat treatment temperature for a time sufficient to achieve desired mechanical properties thereof. Thereafter, the castings generally will be removed and transferred to a quench unit or station **28**, which can be part of or can be a separate station positioned adjacent or downstream from the vertical heat treatment unit **10** as illustrated in FIG. **2**A.

[0039] As indicated in FIG. **2**B, the castings can be transferred from their pouring stations **12**, either within their molds or after removal and placed on a transfer line **31**, such as a monorail or similar conveying mechanism, that transfers or conveys the castings in series or in batches to one or more loading carousels **32**. The carousels **32** generally can include a series of receiving bins or trays **33** and a transfer mechanism **34** such as a robot, crane, boom, or other similar device. The transfer mechanism **34** then feeds the castings, or the molds with the castings therein, into one or more vertical heat treatment units **10** for solution heat treatment of the castings.

[0040] It has been discovered that as the metal of the casting is cooled down, it reaches a temperature or range of temperatures referred to herein as the "process control temperature" or "process critical temperature." Below such process control temperature(s), the time required to both raise the castings to the heat treating temperature and perform the heat treatment is significantly increased. It will be understood by those skilled in the art that the process control temperature for the castings being processed by the present invention will vary depending upon the particular metal and/or metal alloys being used for the castings, the size and shape of the castings, and numerous other factors.

[0041] In one aspect, the process control temperature may be about 380° C.-480° C. and as low as about 300° C.-325° C. or less for some alloys or metals. In another aspect, the process control temperature may be from about 400° C. to about 600° C. In another aspect, the process control temperature maybe from abut 800° C. to about 1100° C. In still another aspect, the process control temperature may be from about 1000° C. to about 1300° C. or more for some alloys or metals, for example, iron. In one particular example, an aluminum/copper alloy may have a process control temperature ranging from about 300° C. to about 480° C. In this example, the process control temperature generally is below the solution heat treatment temperature for most aluminum/copper alloys, which typically is from about 427° C. to about 495° C. While particular examples are provided herein, it will be understood that the process control temperature will vary depending upon the particular metal and/or metal alloys being used for the castings, the size and shape of the castings, and numerous other factors.

[0042] When the metal of the castings is within the desired process control temperature range, the casting typically will be cooled to sufficiently solidify as needed or desired. For example, depending on the alloy formation or metal composition of the castings, castings made from aluminum alloys generally will need to cool to about 460° C.-425° C. to enable sufficient solidification so that the castings can be gripped and manipulated, i.e., removed from their molds/dies and/or transferred to the vertical heat treatment unit or line as needed. This solidification temperature will be understood as varying and can be determined as understood by those skilled in the art based on the formulation(s) of the metals or metal alloys being cast. However, if the metal of the castings is permitted to cool below its process control temperature, it has been found that the heat treatment time for the casting is meaningfully impacted. For example, for some metals or metal alloys, the castings may need to be heat treated for at least about one to four additional minutes of heat treatment time for each minute that the temperature of the metal of the castings is cooled below the process control temperature, for example, from about 475° C. to about 495° C. for aluminum/copper alloys, or from about 510° C. to about 570° C. for aluminum/magnesium alloys, to achieve the desired heat treatment properties for the castings. Thus, if the castings cool below their process control temperature for even a short time, the time required to heat treat the castings properly and completely may be increased significantly.

[0043] In addition, it should be recognized that in a batch processing system, where several castings are processed through the heat treatment station in a single batch, the heat treatment time for the entire batch of castings generally is based on the heat treatment time required for the casting(s) with the lowest temperature in the batch. As a result, if one of the castings in the batch being processed has cooled to a temperature below its process control temperature, for example, for about ten minutes, the entire batch typically will need to be heat treated, for example, for as much as at least an additional forty minutes or more to ensure that all of the castings are heat treated properly and completely.

[0044] Various aspects of the present invention therefore, are directed to an integrated processing facility or system **5** (FIG. **2**A-**2**B) and methods of processing metal castings. The various systems are designed to move and/or transition the castings (within or apart from their molds) from the pouring station **12** to the vertical heat treatment system or cell unit **10**, while arresting cooling of the molten metal to a temperature at or above the process control temperature of the metal, but below or approximately equal to the desired heat treatment temperatures thereof to allow the castings to solidify. Accordingly, various aspects of the present invention include systems for monitoring the temperature of the castings to ensure that the castings are maintained substantially at or above the process control temperature.

[0045] For example, thermocouples or other similar temperature sensing devices **36** (FIG. **2**A) or systems can be placed on or adjacent the castings at spaced locations along the path of travel of the castings from the pouring station to a vertical heat treatment unit or cell unit **10** to provide substantially continuous monitoring as indicated in FIG. **2**A. Alternatively, periodic monitoring of the castings along their path of travel at selected intervals determined to be sufficiently frequent, may be used. Such sensing devices may be in communication with a controller **37** that can be linked to and in control of one or more heat sources **38** positioned at desired or predetermined locations along the path of the castings from the pouring station **11** to the vertical heat treatment unit **10**.

For example, the heat sources could be positioned at desired locations such as along the transfer line **31** (FIG. **2**B). A heat source also can be positioned on or adjacent the robot or other transfer mechanism **34** for the loading carousel(s) **32** for applying heat to the castings during transfer to the vertical heat treatment unit.

[0046] The temperature measuring or sensing device(s) **36** and the operation of the heat source(s) **38** can be controlled or coordinated to substantially arrest cooling of the castings and apply heat as needed to maintain the temperature of the castings substantially at or above the process control temperature for the metal of the castings. It also will be understood that the temperature of the castings can be measured at one particular location on or within the castings, can be an average temperature calculated by measuring the temperature at a plurality of locations on or within the castings, or may be measured in any other manner as needed or desired for a particular application. Thus, for example, the temperature of the castings may be measured at multiple locations on or in the casting and/or mold therefore, and an overall temperature value may be calculated or determined to be the lowest temperature detected, the highest temperature detected, the median temperature detected, an average of the detected temperatures, or any combination or variation thereof.

[0047] A first embodiment of the integrated facility **5** and vertical heat treatment system or cell unit **10** for processing metal castings therethrough is illustrated in FIGS. **1**, **2**A, **2**B, and **4**-**6**C. FIGS. **8**A-**11**C illustrate additional, alternative embodiments of the vertical heat treatment unit **110**, **150**, and **200**, respectively, for heat treating castings. Still further, FIGS. **7**A-**7**C illustrate various nozzle configurations for fluid media nozzles/applicators for applying heat to the castings in the vertical heat treatment units according to the present invention. It also will be understood by those skilled in the art that the principles of the present invention can be applied equally to batch type and continuous processing type facilities for castings. The embodiments described hereinafter therefore are not and should not be limited only to continuous or batch-type processing facilities. The present invention also can be utilized for facilities in which the castings are to be removed from their dies before heat treatment, as well as for "2-in-1," 3-in-1," and/or "6-in-1" or other, similar processes wherein the castings are placed in the vertical heat treatment unit while still inside their sand molds for breakdown, removal and/or reclamation of the molds and sand cores in conjunction with heat treatment of the castings. In addition, it further will be understood by those skilled in the art that various features of the embodiments discussed hereafter and illustrated in the drawings can be combined to form additional embodiments of the present invention.

[0048] In an exemplary system as illustrated in FIGS. **2**A and **2**B, the castings are transferred, either remaining within their molds or after removal therefrom, from the transfer positions **26** (FIG. **2**A) of their pouring stations **12** to the transfer line **31** or directly to an adjacent vertical heat treatment unit **10** by a transfer mechanism **34**. The transfer system or mechanism **34** typically includes a robotic arm **39** or crane, although it will be understood by those skilled in the art that various other systems and devices for moving the castings and/or molds, such as an overhead boom or hoist, conveyor, pushing rods, or other similar material handing mechanisms also can be used. As indicated in FIG. **2**A, the robotic arm **39** or other transfer mechanism generally includes an engaging or gripping portion or clamp **41** for engaging and holding the molds or castings, and a base **42** on which the robotic arm is pivotally mounted so as to be moveable between the transfer point **26** (FIG. **2**B) of the pouring station and the transfer line indicated by **31**. In addition, as shown in FIG. **2**B, the transfer line **31** also can be used to transfer molds and/or castings from multiple pouring stations **12** to multiple vertical heat treatment units **10**.

[0049] The castings can be transferred from their pouring station(s) **12** to a loading carousel **32**, where an additional transfer mechanism **34** such as a robotic arm, crane, boom, or similar mechanism, such as already in use at the facility, generally will pick up the molds with their castings contained therein, or can remove the castings **13** (FIG. **3**) from their molds **11** and feed the castings to an associated vertical heat treatment unit **10**. Thus, the same manipulator or transfer mechanism can be used for removing the castings from the pouring station and for introducing the castings into the vertical heat treatment unit **10**. Additionally, one or more heat sources or heating elements **38** (FIG. **2**A) can be positioned adjacent the transfer point (not shown) and/or along the transfer path for the castings to apply heat to the castings as needed to maintain the castings at or above their process control temperatures. These heat sources typically can include any type of heating element or source such as conductive, radiant, infrared, convective, and direct impingement types of heat sources. As illustrated in FIG. **2**A, multiple heat sources also can be used, positioned to most effectively apply heat to the castings during a transfer operation from the pouring station to the heat treatment line.

[0050] Typically, in the case of permanent or metal dies or molds, the molds will be opened at the transfer point and the castings removed by the transfer mechanism. The same transfer mechanism then can transfer the castings to the transfer line **31** or directly to one or more vertical heat treatment units or systems **10** of the integrated processing facility **5**. As the molds are opened and the castings removed, the heat sources can apply heat directly to the castings to arrest or otherwise control the cooling of the castings during their exposure to the ambient environment of the foundry or plant, as the castings are being transferred to the heat treatment unit, to maintain the castings substantially at or above the process control temperature of the metal of the castings.

[0051] For the processing of castings that are being formed in semi-permanent or sand molds, in which the castings typically remain within their molds during heat treatment, during which the molds are broken down by the thermal degradation of the binder material holding the sand of the mold, the transfer mechanism may transfer the entire mold with the casting contained therein, from the transfer point to the inlet conveyor. The heat source thus may continue to apply heat to the mold itself with the amount of heat applied being controlled to maintain the temperature of the castings inside the mold at levels substantially at or above the process control temperature of the metal of the castings without causing excessive or premature degradation of the molds.

[0052] A first embodiment of the vertical heat treatment unit or cell unit of the present invention generally is illustrated in FIGS. **4**-**6**C. As shown, the vertical heat treatment unit **10** generally can be a vertically oriented, free-standing "cell unit," according to the invention, having a significantly reduced footprint such that the amount of plant floor space required is minimized, while still accommodating a desired amount of castings to be processed. The vertical heat treatment unit thus also can be positioned in close proximity to the pouring station(s) supplying castings thereto. In the present embodiment shown, the vertical heat treatment unit can be approximately 20-30 feet in height, although each vertical heat treatment unit also can be constructed with greater or lesser heights depending upon the required capacity and/or sizes of the castings being processed.

[0053] The vertical heat treatment unit **10** includes an upstanding furnace **50** supported by a surrounding frame **51**. As previously noted, the furnace can be formed with varying heights and typically can be approximately 20-30 feet in height, with the height and width of the furnace chamber being varied as needed and generally being designed to accommodate a desired number of castings, i.e., 10-20 or more rows of 1-5 castings generally received in each row or batch for batch processing, although the castings also can be processed individually or in larger batch sizes as needed or desired. The vertical orientation and ability to vary the height of the furnace chamber of the vertical heat treatment unit **10** of the present invention depending upon the application and/or facility/setting for its use, thus can enable up to an approximately a 75% smaller footprint over many conventional heat treatment units.

[0054] As shown in FIGS. **4**-**5**A and **6**B, the furnace **50** includes a top portion **52**, substantially flat side walls **53**, the interior surfaces **54** (FIGS. **5**A and **6**B-**6**C) of which typically will be formed from or lined or coated with a radiant material so as to reflect direct heat inwardly toward the castings. The radiant material of the radiant interior walls or surfaces **54** may be metal, telefilm, ceramic, composite or other similar high temperature enduring material capable of radiating heat. These radiant coatings or materials generally form a non-stick surface on the walls and ceiling of the furnace, and as the walls and ceiling of the radiant chamber are heated, the heat tends to radiate inwardly toward the castings, while at the same time, the surfaces of the walls and ceiling generally can be heated to a temperature sufficient to burn off waste gases and residue such as soot, etc., resulting from the combustion of the binders of the sand molds and/or sand cores to prevent collection and buildup thereof on the walls and ceiling of the radiant furnace. The furnace **50** further includes a lower or bottom portion **56** having inwardly sloped side walls **57** that terminate at a substantially flat bottom **58**. As indicated in FIG. **6**B, the lower portion **56** also can include a fluidizer **59** positioned therealong for fluidizing and assisting in substantially completing the breakdown of the remaining binder materials from the sand being collected from the sand cores and sand molds of the castings, and a conveying mechanism **61** (FIG. **6**C) for thereafter transporting the reclaimed sand away for reuse.

[0055] As also indicated in FIG. **6**B, the furnace **50** further can include upper and lower sections **62** and **63** that serve to help define a radiant furnace chamber **64** through which the castings **13** are conveyed for heat treatment and/or de-coring and mold removal. As further indicated in FIG. **6**B, the upper and lower portions **62** and **63** taper or slope inwardly, with the upper sections **62** defining a narrowed upper air passage **66** for the passage of heated air flows directly therethrough, while the lower section **63** defines a narrow outlet passage **67** through which sand from the sand cores and/or sand molds of the castings is directed into the bottom or lower portion **56** of the furnace **50**. Still further, as indicated in FIGS. **5**A-**5**B, and **6**B, an inlet/outlet port or opening **69** generally is formed through one of the side walls **53** (FIG. **6**B) and radiant walls **54** for ingress and egress of the castings into and out of the furnace chamber **50**. A door or other cover mechanism **71** is provided for controlling access to the furnace.

[0056] As additionally indicated in FIGS. **4**, **6**A, and **6**B, a manipulator **75** will be mounted along one side of the vertical heat treatment unit **10** in a position for receiving the castings from their associated loading carousel **32** (FIG. **2**B) or directly from the transfer line **31**. The manipulator **75** generally is moveable horizontally and vertically as needed to lift, move, insert, and withdraw the castings into and out of the furnace. As indicated in FIGS. **4** and **6**B, the manipulator **75** typically includes one or more lift plates or forks **76** mounted to a motorized carriage **77** that can ride on guide rails **78** for picking up and moving the castings into the port or opening **69** (FIG. **6**B) of the furnace chamber **50**.

[0057] As indicated in FIGS. **5**A-**5**B and **6**B, within the radiant chamber **64** of the furnace **50** of the vertical heat treatment unit **10** is a vertically oriented carousel or "ferris wheel" type conveying mechanism **81** having a series of platforms, racks, or trays **82** (hereinafter, collectively, the "tray") mounted on chains **83** that are rotated around large drive sprockets **84**/**84'** driven by variable speed, reversible motors (not shown) for driving the conveying mechanism **81** at varying speeds and in a stepped fashion. Typically, for loading/unloading operations, as the castings **13** are received within the furnace **50**, and/or after removal of a group or set of heat treated castings, the conveying mechanism **81** generally will be operated in a controlled stepping, up and down type motion, i.e., moving the rocks of the conveying mechanism (in direction of arrow **86'** of FIG. **6**B) to load a next casting or series of castings therein, up one position and after the castings are received therein, rotating the conveying mechanism downwardly so a to move the racks or sets of racks two positions up from the just-loaded rack(s) into a position for unloading, as needed, heat treated castings therein, (in the direction of arrow **86**, FIG. **6**B) during loading and unloading operations. Thereafter during normal operation, the castings will be conveyed in a substantially elliptical path down and around the lower sprocket **84'** and upwardly and over the upper sprocket **84** for heat treatment. The stepping up one, down two, motion of the conveying mechanism helps ensure a sufficient separation between the incoming ("colder") castings and the hottest castings within the furnace to help substantially reduce or prevent heat transfer/loss between the hottest and "colder" castings to enable completion of the heat treatment of such hotter castings.

[0058] As further illustrated in FIGS. **4**-**6**C, the furnace **50** generally includes one or more heat sources **90**, here illustrated as fans or blowers **91** positioned adjacent the upper end of the furnace **50**. The blowers **91** direct a heated media such as air or other gases or fluids into the furnace so as to create a turbulent heated fluid flow that passes about the castings as the castings are conveyed along their heat treatment path by the conveying mechanism **81** (FIGS. **5**A, **5**B, and **6**B). The blowers or fans **91** further can be utilized in conjunction with other heat sources such as radiant or infrared heaters, gas fired burners or other types of heat sources to create a heated environment within the furnace for heating the castings to their solution heat treatment temperature. In addition, where the castings are processed in their sand molds, the application of heat and the turbulent heated fluid flow about the castings and downwardly to the bottom of the furnace **50**, as indicated in FIGS. **6**B and **6**C, helps facilitate the decomposition and combustion of the binder materials of such sand cores and sand molds so as to cause them to combust, pyrolize or otherwise be driven off and the sand removed from the castings and directed downwardly to the lower portion **56** of the furnace for collection and removal as indicated in FIG. **6**C.

[0059] In another aspect, additional or alternative heat sources **90** can be mounted within the radiant walls **54**, positioned at desired intervals therealong for directing high pressure fluid flows at the castings within the trays of the conveying mechanism, as illustrated in FIG. **6**B, or as conveyed individually or in discrete groups, such as illustrated in FIGS. **9**A-**11**B. These heat sources **90** can include high velocity blowers or nozzle assemblies **92** positioned at desired distances with respect to the known center-lines of the castings, including high pressure blowers or nozzles positioned at desired distances with respect to the known center-lines of the castings as they are conveyed within the trays **82** of the conveying mechanism **81**, through the radiant chamber of the furnace. The location and design of the nozzle or blower assemblies **92** along the radiant walls **54** of the furnace **50**, as well as the actual distance that the pressurized fluid media directed from such blowers needs to travel to impinge the castings and/or the sand cores within the castings, such as passing through core openings therein, the design of the flow pattern, the fluid media, and other flow parameters of the fluid media directed from the nozzle openings or ports **93** (FIGS. **7**A-**7**C) generally will depend on the type and size of the work piece, as well as the size of the nozzles themselves.

[0060] According to one aspect of the invention, at least one of the nozzles **92**, blowers or other impingement devices can have a nozzle opening or port **93** in the range of about ⅛ inch to about 6 inches in diameter or width, and in particular, the nozzles can have one or more openings or ports **93** having a diameters of less than about 1-1.5 inches to about 4 inches and can extend a length of approximately 10"-26" depending on the distances from the nozzles to the castings. The diameters of the nozzle openings or ports **93** can be fixed, although variable size nozzles also can be used, and further will be dependent upon the desired or needed velocities of the fluid media flows striking or impinging the castings and their sand cores as desired or needed, as well as the size of the core openings at which and through which the fluid flows are directed. Alternatively, as indicated in FIGS. **7**A and **7**B, the nozzles **92** also can include an elongated slotted opening or port **94** for applying a broader or extended fluid flow along an expanded area or over a series of locations rather than more localized applications to specific points or areas of the castings. Accordingly, while certain nozzle opening configurations, widths and/or ranges of widths or diameters are set forth herein, it will be understood by those skilled in the art that any suitable impingement device or nozzle diameter and/or configurations can be used in accordance with the present invention to achieve the desired results. Thus, other nozzle opening diameters and/or configurations are also contemplated hereby.

[0061] FIGS. **7**A-**7**C illustrate various nozzle configurations or arrangements for applying the heated fluid media to the castings. In one embodiment shown in FIG. **7**A, an upper nozzle assembly **92**A is formed with a series of large, medium or small nozzle openings or ports **93** arranged at selected locations along the plenum **95**. Typically, the nozzle ports of the upper nozzle generally will be arranged at locations approximately corresponding to the core openings or other desired locations formed along the upper surface of the casting, so as to apply a heated fluid media, such as heated air or other fluids, primarily directed at selected locations and/or providing fluid velocity flows across the remainder of the upper surface of the castings. As also indicated in FIG. **7**A, a lower nozzle assembly **92**B generally will be positioned beneath the casting for applying heated fluid media flow at the bottom or lower portion of the casting. In the embodiment illustrated in FIG. **7**A, the lower nozzle assembly **92**B generally comprises a slotted nozzle port **97** having an elongated slotted opening. The slotted nozzle port **97** can extend substantially along the length of its plenum **95**, typically for a length approximately equivalent to the largest or longest casting to be treated. For example, the slotted opening **94** can extend approximately 10-15 inches in length (although greater or lesser lengths also can be used), and generally can be approximately 0.5 inch to 1 inch wide, although greater or lesser widths also can be utilized depending upon the penetration velocities desired or needed by the fluid media flow being applied by the nozzle assembly **92**B.

[0062] FIG. **7**B illustrates a further example embodiment of a nozzle configuration arrangement **92** that can be utilized in the vertical heat treatment unit according to the principles of the present invention. In this embodiment, a series of four nozzle assemblies **92**A-**92**D are indicated, although greater or lesser numbers of nozzle assemblies also can be used. The upper or top nozzle assembly **92**A is shown with a series of varying size nozzle ports or openings **93**/**93'**, which further can be arranged as singles for directing fluid flows towards specific locations or openings along the upper top surface of the casting. The remaining nozzle assemblies **92**B-**92**D are illustrated at having slotted openings **94**, and are arranged or positioned along the bottom and side surfaces, respectively, of the casting. Such a nozzle assembly can be provided in a chamber or along a conveyor or other guiding mechanism, along which the castings are conveyed through various embodiments of the vertical heat treatment unit such as discussed more fully below with respect to the embodiments of the vertical heat treatment unit as illustrated in FIGS. **8**A-**11**D. The nozzle assemblies **92**B-**92**D (FIG. **7**B) are illustrated with a slotted nozzle openings **94**, although it will be understood that one or more of the additional nozzle assemblies can be provided with individual, localized ports or openings, and similar configurations to that of the upper nozzle assembly **92**A.

[0063] FIG. **7**C illustrates yet another example embodiment of a nozzle arrangement in which an upper nozzle assembly **92**A is positioned above the upper surface of a casting, while a lower nozzle assembly **92**B applies a heated fluid media flow across desired locations along a bottom surface of the casting. In this embodiment, the upper nozzle assembly includes ports or openings **93**/**93'** and can comprise small, medium, or large diameter openings or ports and are generally spaced along or across the upper surface of the castings for applying heated fluid media at varying velocities across or at differing locations along the upper surface of the casting. For example, smaller diameter nozzle ports **93'** can be oriented or focused at core openings or recesses so as to provide a high velocity, heated fluid flow at such core openings for breaking up and dislodging sand cores, while the larger diameter ports or openings **93** can provide heated media fluid flow over a larger area or wider location along the upper surface of the casting. Additionally, the lower nozzle assembly **92**B is shown with a series of small or medium diameter nozzle ports or openings **93'** (although larger diameter nozzle ports or openings also can be used) in which nozzle ports are arranged at angles. Such nozzle ports can be of varied lengths and be oriented at an angle with respect to the bottom surface of the casting and can apply a high velocity fluid flow across a larger area, or can be specifically directed to certain locations, such as core openings in the castings, as needed.

[0064] According to another aspect of the present invention, the nozzle ports or openings **93**/**93'**/**94** generally can be positioned from about 1-1.5 inches to about 10 inches or more away from the castings, and more typically, can be located about 1 inch to about 6-8 inches from the casting in order to impinge and or blast fluid into and around the molds, castings, and/or sand cores of the castings so as to direct substantially full velocity or pressure of the fluid media exiting the nozzle openings being substantially maintained. Typically, it has been found that substantially the full speed or velocity and/or pressure of the fluid media being applied by the nozzles can be maintained at a distance from the nozzle opening that is approximately five-seven times the diameter of the nozzle. For example, if the nozzle opening is approximately one inch in width or diameter, the full velocity of the fluid flow generally will be substantially maintained for approximately five-seven inches, after which the velocity will begin to significantly dissipate or decrease. Thus, the nozzles generally are positioned at locations spaced from known or projected center-lines of the castings as the castings are conveyed within the trays **82** (FIG. **5**B) of the conveying mechanism **81** by a distance of approximately five-seven times the nozzle opening diameter. It will, however, be understood that while various distances and ranges of distances are provided herein, each nozzle or impingement device may be positioned at varying distances with respect to the center-lines of the castings being processed or from a desired point or area of effect of the fluid flow as needed to achieve the desired results. Thus, numerous other possible positions or separation distances between the castings and the nozzle are contemplated hereby.

[0065] The fluid media applied by the nozzles **92** generally is delivered at a high discharge flow velocity of approximately 4,000-40,000 feet per minute (ft/min), for example, in a range of about 5,000-9,000 ft/min (approximately 50 m/sec) so as to impinge against the castings and/or create a turbulent high temperature, high velocity fluid flow through the furnace chamber. It also will be understood that while there are velocities and ranges of velocities provided above, other velocities also can be used in accordance with the present invention, depending, for example, upon the size and type of casting, to achieve the desired results. The fluid media thus generally can be delivered to the castings and/or the core contained therein at a rate of approximately 50-500 standard cubic feet per minute per foot from the nozzles, although other flow rates also can be utilized or provided.

[0066] As a result, the fluid media is delivered to the castings, and more particularly to the core openings at a substantially high velocities so as to create significant turbulence and to enhance the burnout of the binder materials for the sand cores and/or sand molds of the castings to enhance the rapid breakdown thereof. The velocities of the fluid flows also can be varied by the pressure and volume of the fluid flow as well as the configurations and sizes of the nozzle ports or openings. In addition, the fluid media flow may be directed to specific portions of the castings and/or sand molds to localize the fluid flows where needed. For example, the fluid media may be directed at one or more faces of the castings to enhance the effect of the impinging fluid media, including being directed at the core openings to enhance the breakdown and removal of the sand cores from the castings.

[0067] The following Table 1 illustrates a comparison of various options or examples of different nozzle configurations. The fluid media flow is applied in volumes of approximately 10.86 pounds per minute of heated air from the upper or top nozzle assembly, and similarly, approximately 10.86 pounds per minute of heated air through the bottom or lower nozzle assembly, with the nozzles arranged in configurations similar to those illustrated in FIGS. **7**A and **7**C. The temperature of the heated air being applied was approximately 1000° F. or more.

Example 1
(4) 1.5" diameter round nozzles at the top of the casting
(4) 1.5" diameter round nozzles at the bottom of the casting
(8) 0.5" diameter round nozzles along the bottom of the casting
The 1.5" bottom nozzles were placed under the fire place of the casting to get better air penetration. The 0.5" bottom nozzles are placed below the intake ports which are around the fireplace of the casting.
Example 2
(1) 0.5" wide × 15" long slot along the top of the casting
(1) 0.5" wide × 15" long slot along the bottom of the casting
Example 3
(8) 1" diameter round nozzles at 2" spacing along the top of the casting
(8) 1" diameter round nozzles at 2" spacing along the bottom of the casting
The bottom nozzles were generally centered on the fireplace of the casting
Example 4
(8) 1" diameter inclined round nozzles along the top of the casting
(1) 0.5" wide × 15" long slot along the bottom of the casting
Example 5
(1) 0.5" wide × 15" long inclined slot along the top of the casting
(1) 0.5" wide × 15" long slot along the bottom of the casting

-continued

	Air Velocity through Casting Cavities (fpm)				
	Example 1	Example 2	Example 3	Example 4	Example 5
Velocity of impingement on upper side (under nozzle)	6000	4000-4500	4500-5500	3000-3800	3000-4500
Velocity of impingement on upper side (between nozzles)	3000-4000	N/A	2000-2300	2000-3000	3000-4500
Velocity of impingement on upper side (under riser)	N/A	1000-2000	N/A	N/A	N/A
Air Velocity in upper area opposite the nozzles	4000-4800	3000-3500	2800-3200	1000-2500	900-1800
Velocity in the vertical passages connecting top and bottom	2000-4000	2000-4000	2300-4000	800-1000	1000-1300
Best case velocity in exhaust ports	8500	6800	4000-5500	4000-5800	3500-5400
Worst case velocity in intake ports	8500	6800	2100-3400	N/A	N/A
Best case velocity in intake ports	8500	6800	3000-4900	2000-4800	2000-5000
Worst case velocity in intake ports	8500	6800	1800-2200	N/A	N/A

[0068] According to the velocities measured in the table, the highest fluid flow velocities were achieved with the nozzle configurations of Examples 1 and 2. However, given the general configuration of most conventional types of castings that typically will be treated in the vertical heat treatment units of the present invention, it has been found that a combination of nozzle configurations as disclosed in Options or Examples 1 and 2, including the use of a slotted nozzle assembly along the bottom or lower side of the casting and an upper nozzle assembly generally having a series of nozzle openings or ports ranging from approximately 0.5 to about 1.5 inches or larger in diameter and arranged at desired locations across the upper surface for providing localized and higher velocities across the upper surface of the castings, generally can provide preferred heating coverage. It will be understood by those skilled in the art, however, that such nozzle configurations can be further varied, as needed, depending on the design or configuration of the castings being treated, and can provide additional heat treatment to certain desired areas or locations of the castings as needed.

[0069] Still further, as indicated by arrows **98** and **98'** in FIGS. **7**A and **7**B, the castings, or the nozzles themselves, or both, also can be oscillated, rotated, or otherwise moved at predetermined intervals or through predetermined motions based upon the known positioning of the castings, including the known center-line positions thereof. Such oscillation of the nozzles and/or the castings during application of the heated fluid flows has been found to provide expanded fluid media impingement across the castings and thereby achieve enhanced efficiency of the process. Depending upon the sizes of the nozzles and the castings themselves, the nozzles or the castings can be moved or oscillated at rates ranging from about 5 feet per minute to upwards of approximately 40 feet per minute, although other rates of movement also can be used in accordance with the present invention to achieve the desired results. Still further, the oscillation of the castings and/or nozzles can be limited from about 3 inches to about 15 inches, up to about 36 inches in either direction, and can be done relatively quickly, i.e., in about 2 seconds per revolution to about 1 minute or at more controlled rates from about 1 minute to about 10 minutes. However, it also will be understood that the oscillation distances and cycle times can be varied as needed to achieve the desired results.

[0070] Additionally, the temperatures of the fluid media being directed at the castings by the nozzle assemblies or blowers **92** generally will be at elevated temperatures, typically from about 400° C. to about 600° C., or more depending upon the metal or metal alloy being treated. The temperatures of the fluid media being applied generally will be sufficient to promote and/or cause the combustion (for example where air or oxygenated gas flows are used for the fluid media) or pyrolyzing of the binder materials of the sand cores and/or sand molds of the castings and to help assist in heat treatment, but generally will be less than the temperature at which the castings might be softened or substantially raised above their solution heat treatment temperature so as to potentially cause damage thereto. It also will be understood that while a particular temperature range is discussed herein, other temperatures also may be used to achieve the desired results.

[0071] As further shown in FIG. **6**C, a separator **96** also can be provided adjacent the furnace **50**. The separator **96** can be a cyclonic separator that is in flow communication with the lower portion or bottom **56** of the furnace **50**, so as to draw off excess air therefrom. As this waste air is passed through the separator **96**, it will be filtered and thus substantially cleaned of particulate matter such as sand, dust, and other debris. Thereafter, the cleaned air can be re-circulated back to the fans or blowers **91** at the top of the furnace **50** where it can be cleaned and reused/redirected into the furnace or can be exhausted or otherwise vented therefrom.

[0072] As shown in FIGS. **4** and **6**B, the vertical heat treatment unit additionally can be provided with a quench unit **28** mounted adjacent or in front of the door **71** to the furnace **50** along the path of movement of the castings into and out of the furnace by the manipulator **75**. The manipulator **75**, after removal of the castings from the furnace chamber of the vertical heat treatment unit, can lower the castings into the quench unit **28** for quenching the castings, and thereafter can remove the castings and deposit them on the transfer line **31** (FIG. 2B) or other conveyance for removal.

[0073] In an alternative embodiment of the vertical heat treatment unit **110** shown in FIGS. **8**A-**8**B, the vertical heat treatment unit **110** includes a furnace **111** having walls **112**, ceiling **113**, and a lower portion **114**, that includes downwardly sloping sections or walls **116** that terminate at a bottom or floor **117**. The walls, ceiling, and lower portion of the furnace **111** generally are formed from or coated with a radiant material as discussed above with respect to the embodiment of FIGS. **4**-**6**C, and define a radiant furnace chamber **118** therein. A series of longitudinally extending conveyors **119**, which can include chain or slotted/belted conveyors having a series of openings or slots **121** (FIG. **8**B) defined therein will be positioned in a vertically stacked arrangement. Each of the conveyors **119** will extend longitudinally along the radiant chamber **118** of the furnace **111** as indicated in FIG. **8**B and will be operated at a desired rate as needed to complete the heat treatment of the castings as they are passed through the radiant furnace chamber **118**. It will be understood by those skilled in the art that while only 2-3 conveyors **119** are illustrated in FIGS. **8**B and **8**A, respectively, additional conveyors also can be provided in a vertically stacked arrangement, with the furnace **111** of the vertical heat treatment unit **110** being extended or increased in size vertically to enable the loading of additional castings and castings of varying sizes therein.

[0074] As shown in FIG. **8**A, a series of heat sources **122** generally are provided above and between the conveyors **119**. The heat sources can include conduction, convection, infrared or other radiant heat sources, such as gas fired burners, and/or can include nozzles or blowers that direct a flow of heated fluid media to the castings as the castings are passed therebeneath on the conveyors **119** so as to heat the castings to a solution heat treatment temperature for heat treatment of the castings. The fluid media further can be applied at substantially higher velocities from the nozzles as discussed above, with the nozzles or heat sources being placed at pre-determined distances with respect to the centerlines castings, so as to direct fluid flows at desired portions of the castings, for example, at and into core openings thereof to facilitate the breakdown and pyrolization of any binder materials for the sand cores and/or sand molds of the castings.

[0075] As further illustrated in FIG. **8**A, any sand dislodged from the sand cores and/or sand molds of the castings can be collected and directed downwardly into the bottom portion **114** of the furnace or along the downwardly sloping sections of the walls **116** thereof. A fluidizer **123** also can be provided adjacent the floor **117** of the bottom or lower portion **114** of the furnace **111** so as to fluidize any collected sand and help further promote the substantially complete breakdown and burnoff of any remaining binder materials so that the sand materials can be substantially cleaned and reclaimed for further use.

[0076] FIGS. **9**A-**9**D illustrate yet another embodiment of the vertical heat treatment unit **150** according to the principles of the present invention. As illustrated FIGS. **9**A-**9**D, the vertical heat treatment unit **150** generally includes a furnace **151** mounted in the vertically extending, upstanding arrangement and can extend between 10-30 feet in height, although greater or lesser heights also can be used as needed or desired, depending on the application. The furnace **151** generally includes a ceiling **152**, vertically extending side walls **153**, and a lower portion **154** (FIG. **9**B), including downwardly sloping sections or walls **156** that extend inwardly and downwardly toward a floor or bottom **157**. The ceiling **152**, side walls **153**, and lower portion **154** of the furnace **151** are generally formed form or have applied thereto a radiant material, such as discussed above with respect to the embodiment of FIGS. **4**-**6**C, so as to radiate heat inwardly therefrom toward the castings, and define a radiant chamber **158** (FIGS. **9**B and **9**D) within the furnace **151**. Heat sources **159**, such as one or more blowers **161** or fans, or other heat sources such as convection or conduction heat sources, including infrared or other radiant heat sources and/or gas fired burners, etc. also can be used to introduce heat into the radiant chamber and raise the temperature of the castings therein to their solution heat treatment temperature.

[0077] As additionally shown in FIGS. **9**B and **9**C, a grid system **162**, having a series of chambers **163** formed therein, will be mounted within the radiant chamber **158** of the furnace **151**. The chambers of the grid system **162** generally will be spaced apart or separated by walls **164**, typically including insulating and radiant materials to prevent heat transfer or loss from hotter castings to cooler castings that are in adjacent chambers or compartments on the same row of the grid system **162**. The floors and ceilings **166** and **167** of each of the chambers or compartments **163** typically can have a slotted construction, with a plurality of openings formed therein, or can be substantially open, with the castings being received and contained on rails **168** (FIG. **9**C) or similar supports so as to allow free flow of air, heat, and dislodged sand from the sand cores and/or sand molds of the castings to pass therethrough and fall through the entire grid system **162** for collection in the lower portion **154** of the furnace **151**. Additional heat sources also can be provided along the floor and ceiling portions **166**, **167** of each of the chambers **163** to help provide additional, directed heat to the castings. For example, such heat sources can include nozzles that apply high velocity fluid media flows directed at desired portions or sections of the castings, such as at core openings, thereof to help facilitate the breakdown and dislodging of the sand from the sand cores and sand molds of the castings.

[0078] As additionally illustrated in FIG. **9**B and **9**D, in this embodiment of the vertical heat treatment unit **150**, a gantry or elevator type loader **175**, which can include a crane, boom, or robotic arm, generally is provided in the radiant chamber **158** of the furnace **151**. The loader **175** generally includes a platform or support **176** on which one or more castings or molds, here shown as four castings or molds **11**/**13**, are received and will be moved vertically and horizontally for introduction and removal of the castings or batches of castings from the compartments or chambers **163** of the grid system **162**, as illustrated in FIG. **9**B. Typically, the support platform **176** of the loader **175** will include a slot or central opening in which the rails or supports of the chambers **163** can be received for removal of the castings from the support platform of the loader after the loader has inserted the castings into their assigned chamber. As further illustrated in FIG. **9**B, where the castings include risers or supports, the support platform of the loader can include a rail or skid adapted to be inserted within such openings in the castings and insert the castings on the rails for a particular assigned chamber.

[0079] Alternatively, as illustrated in FIG. **9**D, the loader **175** can be positioned outside of the furnace **151**. In this embodiment, the loader **175** will be moveable into and out of the chambers or compartments **163** of the grid **162** through associated compartment openings **180**. Each compartment opening or passage **180** will include a door or cover **181** that is moveable between an open position (as shown in FIG. **9**D) for receiving the castings therein and a closed position for sealing the compartment openings. The doors **181** can be automatically engaged by sensors that activate a motor or hydraulic or pneumatic lift mechanism, or could be engaged and opened by the loader itself via a lift/positioner mechanism or extension on the loader, which contacts and causes the door to open, after which the doors can be allowed to close by gravity.

[0080] FIGS. **10**A-**11**B illustrate still a further embodiment of the vertical heat treatment system or cell unit **200** according to the principles of the present invention. In this embodiment, the vertical heat treatment unit **200** generally is illustrated as including a substantially circular or octagonally-shaped configuration, although other similar configurations also can be provided, and generally includes a furnace **201** having a series of chambers **202**A-**202**D. The furnace **201** can extend to approximately 10-20 feet in height although it also can be formed at greater or lesser heights as needed or desired, depending upon the application, including the types of casting to be processed, as well as the environment in which the vertical heat treatment unit or cell unit is to be placed, while providing a reduced footprint and the ability to place the cell unit in close proximity to the pouring station(s).

[0081] As indicated in FIG. **10**A, each of the chambers **202**A-**202**D can be formed with a substantially C or U-shaped configuration including angled or curved walls **203** having inner surfaces **204** generally formed from or coated with a radiant material, such as a ceramic material or other, similar heat resistant and heat radiating material capable of withstanding high temperatures. The walls **203** further can be hollow so as to define flow passages, indicated by arrows **206**, through which heated fluid flows, such as heated air flows or other similar heated fluid media, are passed.

[0082] As further illustrated in FIGS. **10**A, **10**B and **11**B, a series of heat sources **207**, such as one or more blowers or forced air fans **208**, generally are mounted along outer side walls **209** of the furnace **201** of this embodiment of the vertical heat treatment **200**, with at least one heat source **207** being provided for each of the chambers **202**A-**202**D as indicated in FIGS. **10**A and **10**B. The heat sources **207**, which also can include sources such as convection or conduction heaters, infrared or other radiant sources and/or gas fired burners, etc., introduce heat into each of the radiant chambers **202**A-**202**D, such as via heated fluid media flows passing along the passages, as indicated by **206**, through the walls **203** of each chamber and through openings **211** (FIG. **10**A) formed in the chamber walls **203**.

[0083] It is further shown in FIGS. **10**A, **11**A, and **11**B, each of the furnace chambers **202**A-**202**D generally includes a series of racks or grid storage units **212** on which the castings **13** are received and retained for heat treatment. The racks or grids **212** further can be formed with or be positioned in a series of compartments or heating chambers **213** in which one or more castings are received. The compartments **213** typically include side walls **214** (FIGS. **10**A and **11**B) generally being formed from or coated with insulating and/or radiant materials to prevent heat transfer or loss from hotter castings to cooler castings in adjacent compartments on the same row of racks or grids **212**. The floors and ceilings of the compartments **213** typically can have a slotted or substantially open construction having a plurality of openings formed therein, with the castings being supported on rails or tracks, or similar supports. As a result, a substantially free flow of air, heat, and dislodged sand from the sand cores and/or sand molds of the castings is enabled through the entire rack or grid system **212** of each furnace chamber and/or compartment for collection. The compartments **213** in each of the furnace chambers further can include additional heat sources **215**, such as nozzles, blowers, or other similar heaters for applying heated fluid flows into the compartment, or can include conduction, radiant or other, similar heat sources for applying heat both above and below the castings within each of the compartments.

[0084] As indicated in FIGS. **11**A and **11**B, the furnace **201** farther generally includes a lower or bottom portion **216** below each of the furnace chambers. The bottom portions can have sloped walls to facilitate collection of the dislodged mold/core sand and other materials, such as is shown in FIGS. **11**A, for reclamation and recovery. Additional heat sources also can be provided in the lower portion of each of the chambers, including fluidizers or nozzles that apply high velocity fluid flows through the bed of the collected sand to help facilitate the further combustion of the binder materials of the sand cores and sand molds to help with the further breakdown and recovery of the sand. Such reclaimed sand then can be discharged via a discharge chute **217** and conveying system **218**. Still further, while each of the chambers can be provided with a lower portion collection area **216**, such as shown in FIG. **11**B, the furnace **201** also can be configured so as to have a central collection area **216** at a lower point thereof, whereby the sand from all the furnace compartments is directed to and collected at such a central location.

[0085] As additionally illustrated in FIGS. **11**A and **11**B, in this embodiment of the vertical heat treatment unit **200**, a gantry or elevator type loader **225**, which can include a crane, boom, robotic arm or other similar lifting mechanism, is located approximately within the center of the furnace. The loader is moveable vertically and horizontally, as well as being rotatable or pivotable about a centrally extending axis, for delivering and removing the castings **13** from the compartments **213** of each of the racks or grid systems **212** of the furnace chambers. The loader **225** generally can include a platform or support **226** on which one or more castings or molds with castings therein **13**/**11** are received and carried for introduction and removal of the castings or batches of castings in to/from each of the compartments **213** of each furnace chamber. The support platform **226** further can include clamping rails or similar supports that can engage and clamp the castings from the sides thereof or can engage the castings through one or more core openings. Additionally, a heat source can be mounted so as to apply heat through or along the support platform **226** as needed or desired for helping speed the heating of the castings to their heat treatment temperatures for treatment, and mold and/or sand core removal and reclamation. Still further, if the castings include risers or other supports, the support platform of the loader can include rails or skids adapted to be inserted within such openings or for engaging the risers or supports for loading and unloading operations.

[0086] As illustrated in FIGS. **10**B and **11**A, the loader **225** generally can receive the castings from an inlet mechanism **230**. The inlet mechanism **230** can include a reversible conveyor or series of conveyors **231** in which the castings are fed individually or in batches into the furnace **201**, into a position where they can be engaged by the loader **225**, as indicated in FIG. **11**A. Still further, it is also possible to utilize more than one loader within the furnace to further enhance or increase the efficiency of loading and unloading the castings within the compartments of the furnace chambers for heat treatment and/or sand mold removal and reclamation.

[0087] As illustrated in FIG. **12**, utilizing the vertical heat treatment unit of the present invention, the heat treatment units can be placed immediately adjacent or in close proximity to the pouring stations for the castings, which thus enables more efficient processing and heat treatment of the castings. Through the use of the vertical heat treatment unit according to the present invention, the castings can be removed from their pouring stations and transferred substantially directly to a heat treatment unit without the castings being unduly exposed to the ambient environment that would allow the castings to cool substantially below the process control temperature for the metal or metal alloy from which the castings are being formed.

[0088] It can be understood by those skilled in the art that for any given casting, the desired dendrite arm spacing is substantially constant, with the interdiffusion coefficients of various metals or metal alloys generally being known values. For example, the interdiffusion coefficient (D) of copper and aluminum is on the order of about $6\times10^{-11}cm^2s^{-1}$ at 450° C. and about 7×10^{-12} cm^2s^{-1} at 400° C. As will be understood by those skilled in the art, the ratios of the interdiffusion coefficients can be evaluated to estimate the differences in diffusion and thus corresponding heat treatment times required for castings that are held at varying temperatures. It is further understood that the diffusion distances (which can be correlated to the desired dendrite arm spacings used for certain metal alloys after heat treatment) can be expressed as $L=\sqrt{Dt}$, wherein D=interdiffusion coefficient of a metal alloy at a desired temperature, while t=Time. Accordingly, for a casting for which the metal thereof has a process control temperature of approximately 450° C. (for example) if the casting is allowed to drop below this predetermined process control temperature, and to a temperature of approximately 400° C., it theoretically can take approximately three (3) times longer to heat treat the castings to achieve the desired properties (such as a desired dendrite arm spacing) than if the casting is maintained at or above its process control temperature of approximately 450° C.

[0089] FIG. **12** is a graphical illustration of a comparison of a process for forming a metal casting, including pouring, maintaining the casting at or above its process control temperature from pouring to heat treatment, then heat treating, quenching, and aging the casting, which can be carried out utilizing a vertical heat treatment unit according to the present invention, as compared to a conventional type casting formation process in which the castings are poured, and then heat treated, while the core and sand molds of the castings are removed and broken down/reclaimed at substantially the same time within the heat treatment furnace, and thereafter quenched and later aged. The dark solid line indicates a process utilizing the present invention, while the lighter colored line illustrates the time required to process a casting according to conventional casting processing methods.

[0090] As illustrated in FIG. **12**, with the present invention, by maintaining the casting substantially at or above its process control temperature (PCT) and placing the casting into heat treatment as quickly as possible via transfer to the "cell unit" or vertical heat treatment unit formed according to the present invention, which, due to its size and configuration can be positioned adjacent or substantially in time with one or more pouring stations, heat treatment of the casting can be accomplished in approximately 98 minutes or less, as compared to over two hours for the conventional process. It also can be seen that the casting is generally able to be raised back up to a solution heat treatment temperature more rapidly as compared to a conventional process. Thus, while the conventional process may take upwards of 13-14 hours to finish pouring, solidifying, heat treating, quenching, and aging a casting, the present invention enables a casting to be formed and processed in about less than half that amount of time.

[0091] Accordingly, as part of a casting process system in which the temperature of the castings is monitored and controlled during transition of the castings from pouring to heat treatment so as to maintain the castings at or above a process control temperature for the metal/metal alloys thereof up to heat treatment, the vertical heat treatment system or cell unit of the present invention can not only provide a substantially shorter heat treatment cycle, but also will provide easier maintenance and labor savings and can support increased casting complexity, while at the same time taking up a much smaller footprint within the facility space of the metal processing and thus enabling more diversification of the casting being produced. The vertical heat treatment system or cell unit of the present invention further can allow for the use of high velocity treatment processes for enhancing the de-coring and mold removal from the castings, in addition to enhancing and further speeding of the heat treatment thereof. For example, with the present invention, time for de-coring a casting can be reduced from approximately 2-4 hours to approximately 40-75 minutes, with the entire cycle time required for de-coring and heat treatment of a casting up until quench being reduced to about an hour and a half or less.

[0092] It will be readily understood by those persons skilled in the art that, in view of the above detailed description of the invention, the present invention is susceptible of broad utility and application. Many adaptations of the present invention other than those herein described, as well as many variations, modifications, and equivalent arrangements will be apparent from or reasonably suggested by the present invention and the above detailed description thereof, without departing from the substance or scope of the present invention.

[0093] Additionally, while the present invention is described herein in detail in relation to specific aspects, it is to be understood that this detailed description is only illustrative and exemplary of the present invention and is made merely for purposes of providing a full and enabling disclosure of the present invention. The detailed description set forth herein is not intended nor is to be construed to limit the present invention or otherwise to exclude any such other embodiments, adaptations, variations, modifications, and equivalent arrangements of the present invention, the present invention being limited solely by the claims appended hereto and the equivalents thereof.

What is claimed:

1. A system for forming and heat treating metal castings, the system comprising:

a pouring station for pouring a molten metal into a mold to form the castings; and

a vertical heat treatment unit positioned downstream from said pouring station;

wherein said vertical heat treatment unit comprises:

a furnace oriented in a substantially vertically extending alignment so as to enable a reduction in area occupied by said vertical heat treatment unit, and defining an upstanding a furnace chamber in which the castings are received; and

a series of heat sources positioned along said furnace chamber for applying heated fluid flows into said furnace chamber for conveying the castings to said vertical heat treatment unit.

2. The system of claim **1** and further comprising a transport mechanism moveable between said pouring station to said vertical heat treatment unit for conveying the castings to said vertical heat treatment unit.

3. The system of claim **1** and wherein said vertical heat treatment unit further comprises a vertically moveable conveyor positioned within said furnace chamber for moving the castings along a vertically extending heat treatment path through said furnace.

4. The system of claim **1** and wherein said furnace chamber of said vertical heat treatment unit further comprises a series of compartments arranged in stacked series along said furnace chamber, and in which the castings are loaded for heat treatment, and wherein said heat sources are arranged along floor and ceiling portions of said compartments.

5. The system of claim **4** and further comprising a loader mounted within said furnace chamber and adapted to move the castings into and out of said compartments.

6. The system of claim **4** and wherein each compartment includes an outer door and wherein said vertical heat treatment unit further comprises an externally mounted loader for loading castings into and removing the castings from each of said compartments.

7. The system of claim **1** and further comprising a conveyor extending along a path of travel between said pouring station and said vertical heat treatment unit, and at least one heat source positioned along said path of travel for applying heat to the castings as they are transitioned from said pouring station to said vertical heat treatment unit.

8. The system of claim **1** and wherein said heat sources comprise conduction heaters, convection heaters, radiant heaters, infrared heaters, or fuel fired blowers.

9. The system of claim **1** and wherein said heat sources comprise a plurality of nozzles arranged about said furnace chamber for applying a heated fluid media to the castings for heat treatment of the castings.

10. The system of claim **9** and wherein said nozzles are located approximately 5-7 inches from a centerline of the castings passing through said furnace chamber.

11. The system of claim **9** and wherein at least one of said nozzles comprises a slotted nozzle having a slotted opening extending substantially along its length.

12. The system of claim **9** and wherein at least one of said nozzles comprises a plenum having series nozzle openings spaced therealong.

13. A system for forming castings, comprising:

at least one pouring station in which a molten metal material is introduced into a series of molds;

a plurality of heat treatment cells mounted downstream and in proximity to said at least one pouring station;

wherein said heat treatment cells each comprise a vertically oriented furnace having a reduced footprint to enable said heat treatment cells to be positioned proximate to said at least one pouring station, a plurality of heat sources applying high velocity heated fluid flows to the castings, and a means for retaining the castings within said furnace and in a position to optimize application of the high velocity heated fluid flows to the castings;

a transport system extending along a path adjacent said at least one pouring station and at least one of said heat treatment cells for moving the castings from the pouring station to at least one of said heat treatment cells during which the castings are permitted to solidify.

14. The system of claim **13** and wherein said heat sources comprise a series of nozzles applying high velocity fluid flows directed at the castings, wherein said nozzles are positioned at a distance from an approximate center-line of the castings of about 5-7 times a diameter or width of an opening of the nozzles.

15. The system of claim **13** and wherein at least one of said nozzles comprises a slotted nozzle having a slotted opening extending substantially along its length.

16. The system of claim **13** and wherein at least one of said nozzles comprises a plenum having series nozzle openings spaced therealong.

17. The system of claim **13** and wherein said vertical heat treatment unit further comprises a vertically moveable conveyor positioned within said furnace chamber for moving the castings along a vertically extending heat treatment path through said furnace.

18. The system of claim **13** and wherein each furnace of each of said heat treatment cells comprises a series of compartments in which at least one casting is received and retained for heat treatment, and wherein said heat sources comprise nozzles arranged along upper and lower portions of said compartments for applying the heated fluid flows to the castings along a desired portions thereof.

19. The system of claim **13** and wherein said heat sources comprise nozzles each having ports located a predetermined distance from a centerline of a casting to which said nozzles are applying the heated fluid, based upon a size of said nozzle ports, and applying the heated fluid at a flow velocity of approximately 4,000-40,000 feet per minute.

20. A method of forming and treating castings, comprising:

pouring a molten metal into a series of molds to form the castings;

removing and transferring the molds to a cell unit located proximate to the pouring station for heat treatment;

as the molds are transferred to the cell unit, allowing the molten metal to substantially solidify sufficiently to form the castings;

introducing the castings into the cell unit and subjecting the castings to a high temperature, high velocity fluid media flow;

wherein subjecting the castings to a high temperature, high velocity fluid media flow comprises locating a series of nozzles having one or more nozzle openings at a distance from an approximate center-line of the castings being treated by the series of nozzles of approximately 5-7 times the size of the nozzle openings; and

retaining the castings within the cell unit for a time sufficient to heat treat the castings to achieve desired physical properties of the castings.

21. The method of claim **20** and wherein subjecting the castings to a high temperature, high velocity fluid media flow further comprises applying a heated air flow from the nozzles at a velocity of approximately 4000-40,000 feet per minute.

22. The method of claim **20** and wherein introducing the castings to the cell unit comprises engaging the castings with a loader and loading the castings into selected compartments within the cell unit.

23. The method of claim **22** and wherein the nozzles are positioned along at least upper and lower portions of each of the compartments for applying the high temperature, high velocity fluid media flows to the castings as the castings are retained in their compartments.

24. The method of claim **22** and wherein the nozzles are mounted along the periphery of the cell unit, and introduce a high temperature, high velocity, turbulent air flow through a furnace chamber of the cell unit, and further comprising conveying the castings through the furnace chamber along a path of movement timed to minimize heat loss from the castings therein.

25. The method of claim **24** and wherein conveying the castings through the furnace chamber comprises loading the castings on a carousel and moving the carousel in a stepped motion in forward and reverse directions to provide a desired separation between incoming castings and castings nearing completion of a heat treatment cycle.

26. The method of claim **20** and further comprising maintaining the casting at or above a process control temperature for the metal thereof as the castings are transferred from the pouring station to the cell unit.

27. The method of claim **20** and further comprising oscillating the nozzles and/or the castings as the high temperature, high velocity fluid media flow is applied to the castings from the nozzles.

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