

(22) Date of filing: **13.09.2019**

(71) Applicant: **United Technologies Corporation**
Farmington, CT 06032 (US)

(74) Representative: **Dehns**
St. Bride's House
10 Salisbury Square
London EC4Y 8JD (GB)

(57) A conveyor furnace system (60) is provided that includes a housing (62), a conveyor (66), a vacuum device (64), and at least one heating element (68). The housing (62) may have a first end and a second end. The conveyor (66) may be configured to transit one or more component molds (78) from the first end to the second end. The vacuum (64) device may be configured to selectively produce a below atmospheric pressure within

the housing (62). The at least one heating element (68) may be disposed in the housing (62), and has a first end disposed adjacent the first end of the housing (62) and a second end adjacent the second end of the housing (62). The at least one heating element (68) is configured to provide a vertically tapered heating exposure in a direction from the first end of the housing (62) to the second end of the housing (62).

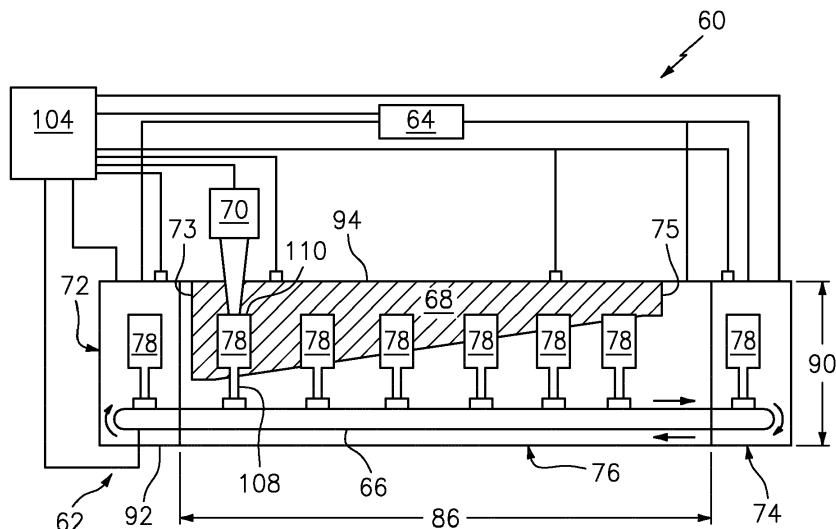


FIG. 3

Description

BACKGROUND OF THE INVENTION

1. Technical field

[0001] The present invention relates to component casting and more particularly but not exclusively to apparatus and methods for casting of directionally solidified components.

2. Background Information

[0002] It is known to use a casting process to produce a wide range of components with complex shapes that would be otherwise difficult or uneconomical to manufacture by other methods. Molten material is poured into a mold that defines the shape of the component. The material is then allowed to cool and solidify in the shape of the mold. Where the material has a melting point well above standard ambient temperature and pressure (SATP) (which is typical for most metals), the pouring of the molten material takes place within a furnace. It is known to control the cooling of the molten material in the mold to control the microstructure of the solidified material.

[0003] It is known to provide multiple components simultaneously by arranging a plurality of molds in a single assembly. In some instances, the molds may be connected by a network of casting channels through which molten material from a casting cup can be fed to the multiple molds simultaneously. Once filled, the molds are collectively drawn from the furnace in a controlled manner.

[0004] For some components (e.g., gas turbine engine turbine blades), it is desirable to produce the component as having a "single crystal" metallurgical microstructure. The term "single crystal" (sometimes called a "monocrystalline") refers to a solid material in which the crystal lattice of the entire body of the material is continuous and unbroken to the edges of the body, with no grain boundaries. A single crystal metallurgical microstructure can be produced, for example, through a process typically referred to as "directional solidification", wherein control is exerted over the nucleation and the growth of single crystals in a molten metal as it passes from its liquid state to a solid state.

[0005] Techniques for producing single crystal components are well known. An example of such a technique is a Bridgman-Stockbarger technique. Within this technique, a mold may contain a seed crystal to initiate a single grain or crystal growth and is gradually withdrawn from the furnace in a direction opposite to that of the desired crystal growth such that the temperature gradient within the molten material is effectively controlled.

[0006] FIG. 1 schematically shows a known apparatus for the simultaneous manufacture of multiple cast components using a directional solidification process. As

shown in the FIG. 1, the apparatus comprises a pouring cup 1 into which molten material M is poured. A plurality of feed channels 2 extend radially around the centrally arranged cup 1 to a top end of the molds 3. Molten material M poured into the cup 1 flows along the feed channels 2 and into the molds 3. Each mold 3 may be provided with a seed crystal 4 at a bottom end of the respective mold 3. Beneath the bottom end of the molds 3 is a chill plate 5 which is generally maintained at a temperature below the melting point of the material M, thereby enabling the creation of a temperature gradient from the bottom to the top of the molds 3. In most instances, the molds 3 are disposed within a furnace having a heat source 6 disposed around the periphery of the furnace. Thus, the heat source 6 encircles the pouring cup 1 and mold assembly. Once the molds 3 are filled with the molten material M, the mold assembly is moved vertically in a controlled manner away from the heat source in the direction of arrow A to ensure directional solidification from the bottom of the molds 3 to the top of the molds 3. The controlled, directional cooling encourages the directional solidification process within the semi-molten casting.

[0007] This type of "batch" casting process possesses a number of different challenges. For example, in many applications a mold assembly configured to produce a substantial number of components in a single batch is used. On the one hand, such a batch process may be efficient in terms of the number of components being cast. On the other hand, such a batch process requires the components to be positioned at different positions within the furnace. Hence, the distance between respective components and the heat source almost always varies. As a result, within the batch, different components are subjected to different thermal environments / thermal gradients. The aforesaid differences within a single batch can undesirably produce components having different metallurgical properties. In addition, in many instances the weight of each individual component mold (which molds are often combined into a single structure) may be substantial when filled. After completion of the process, each filled mold must be removed from the batch device. This can present an ergonomic issue for the operator for those instances when heavy components are being produced, or in those instances when multiple molds are configured together and the collective weight of the filled molds is significant. Also, the inherent nature of the batch processing increases the risk of greater numbers of defective components; e.g., if a batch is not processed correctly, it is likely that all of the components within the batch will be defective. Still further, batch processing is time consuming. The batch device must be set up properly, the molds heated and filled, and then moved relative to the heat source to produce the desired directional solidification. Once the directional solidification process is completed, then the entire structure must be allowed to cool before an operator can access it. Hence, although there may be an efficiency gained in terms of being able to process a number of components in a single

batch, the aforesaid process is not efficient in terms of the amount of time required from beginning to end.

[0008] What is needed is an apparatus and method that improves upon the presently available devices and methodologies for producing directionally solidified components.

SUMMARY

[0009] According to an aspect of the present disclosure, a conveyor furnace system is provided that includes a housing, a conveyor, a vacuum device, and a plurality of heating elements. The housing has a first end and a second end, and the second end is opposite the first end. The conveyor is configured to transit one or more component molds from the first end to the second end. Each component mold has a base end and a top end and a height extending therebetween. The vacuum device is configured to selectively produce a below atmospheric pressure within the housing. The plurality of heating elements are disposed in the housing, and are arranged within the housing so that the one or more component molds transiting through the housing are subjected to a progressively different heating exposure in a direction from the first end to the second end during operation of the system.

[0010] In any of the aspects or embodiments described above and herein, the housing may include a loading station and an intermediate station, and the conveyor may be configured to transit the one or more component molds from the loading station and into the intermediate station, and the plurality of heating elements are disposed in the intermediate station.

[0011] In any of the aspects or embodiments described above and herein, the housing may include an unloading station, and the loading station is disposed at the first end of the housing, and the unloading station is disposed at the second end of the housing, and the intermediate station is disposed between the first end and the second end.

[0012] In any of the aspects or embodiments described above and herein, the loading station, the intermediate station, and the unloading station may be linearly arranged.

[0013] In any of the aspects or embodiments described above and herein, the loading station, the intermediate station, and the unloading station may be non-linearly arranged.

[0014] In any of the aspects or embodiments described above and herein, the vacuum device may be configured to selectively produce a below atmospheric pressure within the loading station, the unloading station, and the intermediate station, all independent from one another.

[0015] In any of the aspects or embodiments described above and herein, the housing may include at least one station configured for loading and unloading component molds.

[0016] In any of the aspects or embodiments described

above and herein, the housing may include an intermediate station that extends arcuately from the at least one station, and the first end of the housing is disposed at the at least one station and the second end of the housing is disposed at the at least one station.

[0017] In any of the aspects or embodiments described above and herein, the progressively different heating exposure may continuously change in the direction from the first end to the second end during operation of the system.

[0018] In any of the aspects or embodiments described above and herein, the progressively different heating exposure may continuously decrease in the direction from the first end to the second end during operation of the system.

[0019] In any of the aspects or embodiments described above and herein, the progressively different heating exposure may change in a stepped configuration in the direction from the first end to the second end during operation of the system.

[0020] In any of the aspects or embodiments described above and herein, the stepped configuration may include a plurality of steps, with each downstream step having a decreased heating exposure.

[0021] In any of the aspects or embodiments described above and herein, the conveyor furnace system may further include a plurality of cooling elements, and the plurality of cooling elements may be arranged within the housing relative to the plurality of heating elements so that the one or more component molds transiting through the housing are subjected to a progressively different heating exposure in a direction from the first end to the second end during operation of the system.

[0022] According to another aspect of the present disclosure, a conveyor furnace system is provided that includes a housing, a conveyor, a vacuum device, and at least one heating element. The housing may have a first end and a second end, which second end is opposite the first end. The conveyor may be configured to transit one or more component molds from the first end to the second end. Each component mold may have a base end and a top end and a height extending therebetween. The vacuum device may be configured to selectively produce a below atmospheric pressure within the housing. The at least one heating element may be disposed in the housing. The at least one heating element has a first end disposed adjacent the first end of the housing and a second end adjacent the second end of the housing. The at least one heating element is configured to provide a vertically tapered heating exposure in a direction from the first end of the housing to the second end of the housing.

[0023] In any of the aspects or embodiments described above and herein, the first end of the heating element has a first vertical heating exposure portion, and the second end of the heating element having a second vertical heating exposure portion, and the first vertical heating exposure portion is greater than the second vertical heating exposure portion.

[0024] In any of the aspects or embodiments described above and herein, the first vertical heating exposure portion and the second vertical heating exposure portion may both extend from adjacent a ceiling of the housing.

[0025] According to another aspect of the present disclosure, a method of producing a directionally solidified component is provided. The method may include: a) heating a component mold within a conveyor furnace system to a predetermined temperature, the conveyor furnace system having a housing with a first lengthwise end and an opposite second lengthwise end, and the component mold having a top vertical end and a bottom vertical end; b) transferring a charge of molten metal into the heated component mold; c) transiting the heated component mold containing the charge of molten metal within the housing from the first lengthwise end to the second lengthwise end; and d) exposing the heated component mold containing the charge of molten metal to a vertically tapered heating exposure in a direction from the first lengthwise end of the housing to the second lengthwise end of the housing.

[0026] In any of the aspects or embodiments described above and herein, the method may further include selectively creating an environment within the housing that is below atmospheric pressure.

[0027] In any of the aspects or embodiments described above and herein, the housing may include a loading station disposed at the first lengthwise end of the housing and an unloading station disposed at the second lengthwise end of the housing, and an intermediate station disposed between the loading station and the unloading station, and the method may further include loading the component mold into the loading station prior to heating the component mold to the predetermined temperature, transiting the component mold from the loading station, through the intermediate station, and into the unloading station, and unloading the component mold from the unloading station.

[0028] In any of the aspects or embodiments described above and herein, the method may further include selectively creating an environment within the loading station that is below atmospheric pressure prior to transiting the component mold from the loading station, through the intermediate station, and into the unloading station.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029]

FIG. 1 is a schematic representation of a prior art batch-type apparatus for producing directionally solidified components.

FIG. 2 is a diagrammatic cross-sectional view of a portion of a gas turbine engine.

FIG. 3 is a diagrammatic front view of a conveyor furnace embodiment.

FIG. 4 is a diagrammatic top view of the conveyor furnace embodiment shown in FIG. 3.

FIG. 5 is a diagrammatic view of a conveyor furnace embodiment.

FIG. 6 is a graph depicting percentage of component mold subjected to a heating element within the intermediate station versus distance traveled within the intermediate station.

FIG. 7 is a graph depicting percentage of component mold subjected to a heating element within the intermediate station versus distance traveled within the intermediate station.

FIG. 8 is a diagrammatic front view of a conveyor furnace embodiment.

FIG. 9 is a graph depicting percentage of component mold (from vertical top) subjected to a heating element and/or a cooling element.

FIG. 10 is a diagrammatic front view of a conveyor furnace embodiment.

FIG. 11 is a diagrammatic front view of a conveyor furnace embodiment.

DETAILED DESCRIPTION

[0030] It is noted that various connections are set forth between elements in the following description and in the drawings. It is noted that these connections are general and, unless specified otherwise, may be direct or indirect and that this specification is not intended to be limiting in this respect. A coupling between two or more entities may refer to a direct connection or an indirect connection. An indirect connection may incorporate one or more intervening entities. It is further noted that various method or process steps for embodiments of the present disclosure are described in the following description and drawings. The description may present the method and/or process steps as a particular sequence. However, to the extent that the method or process does not rely on the particular order of steps set forth herein, the method or process should not be limited to the particular sequence of steps described. As one of ordinary skill in the art would appreciate, other sequences of steps may be possible. Therefore, the particular order of the steps set forth in the description should not be construed as a limitation.

[0031] The present disclosure is not limited to producing any particular type of directionally solidified component. That said, there is particular advantage to producing certain gas turbine engine components (e.g., turbine blades) in a directionally solidified manner. To give an appreciation for such gas turbine engine components and the environment in which they are utilized, a brief description of an exemplary gas turbine engine follows hereinafter. Referring to FIG. 2, a two-spool turbofan type gas turbine engine 20 is shown (e.g., see FIG. 2). This exemplary embodiment of a gas turbine engine includes a fan section 22, a compressor section 24, a combustor section 26, and a turbine section 28. The fan section 22 drives air along a bypass flow path B in a bypass duct, while the compressor section 24 drives air along a core flow path C for compression and communication into the

combustor section 26 then expansion through the turbine section 28.

[0032] The exemplary engine 20 shown in FIG. 1 includes a low speed spool 30 and a high speed spool 32 mounted for rotation about an engine central longitudinal axis A relative to an engine static structure 36. The core airflow is compressed by the low pressure compressor 44 then the high pressure compressor 52, mixed and burned with fuel in the combustor 56, then expanded over the high pressure turbine 54 and low pressure turbine 46. The turbines 46, 54 rotationally drive the respective low speed spool 30 and high speed spool 32 in response to the expansion.

[0033] Core airflow increases in temperature as it travels through the engine. A variety of components that are exposed to high temperature air are often cooled by lower temperature air (e.g., bypass air flow) passing through cooling passages or ducts formed within or between components. Many of these "cooled" components are produced by using a casting process, and include interior cavities for receiving cooling air.

[0034] Aspects of the present disclosure include a conveyor furnace system 60 that includes a housing structure 62, one or more vacuum devices 64 (e.g., a pump), a conveyor 66, one or more heating elements 68, and a material feed system 70. As will be described below, the conveyor furnace system 60 is configured to have one or more component molds 78 transit through the conveyor furnace system 60 from a first end to a second end. Each component mold has a height that extends from a base end 108 to a top end 110. Within the conveyor furnace system 60, the component molds 78 are arranged so that the top end 110 of each component mold 78 is vertically above the base end 108. The present disclosure is not limited to any particular component mold 78 configuration. An example of a component mold 78 configuration is one configured to make a rotary blade for a gas turbine engine; e.g., a turbine blade. The present disclosure is not limited to any particular type of component.

[0035] In some embodiments (e.g., see FIGS. 3 and 4), the housing structure 62 includes a loading station 72, an unloading station 74, and an intermediate station 76 disposed there between. The embodiment shown diagrammatically in FIGS. 3 and 4 has a housing structure 62 having a substantially straight line, linear configuration. The present disclosure is not limited to a substantially straight line, linear configuration. For example, in some embodiments, the housing structure 62 may be arcuately shaped. An example of an arcuately shaped housing structure 62 is a circular housing structure 62 (see FIG. 5). Some circular housing structures 62 may combine the loading and unloading stations 72, 74 into a single station. In such embodiments, the single loading/unloading station would have the functionality described below for loading station 72 as well as the unloading station 74 unless otherwise indicated below.

[0036] The loading station 72 is configured to include

an operator access port 77 (e.g., a door) that allows an operator to insert a component mold 78. The loading station 72 further includes a furnace port 80 that is configured to selectively provide an air pressure barrier (e.g., a door) between the loading station 72 and the intermediate station 76. The furnace port 80 is also configured to permit transfer of a component mold 78 from the loading station 72 to the intermediate station 76 via the conveyor 66. The access port 77 and the furnace port 80 are configured to be sufficiently air tight to allow the interior region of the loading station 72 to be maintained in a vacuum condition (e.g., at a pressure less than ambient) for an acceptable period of time; e.g., at least the amount of time required to transfer the component mold 78 from the loading station 72 to the intermediate station 76 via the conveyor 66. The loading station 72 is in communication with the one or more vacuum devices 64 to permit the loading station 72 to be evacuated to the vacuum condition.

[0037] The material feed system 70 is configured to hold a charge of metal sufficient to fill a component mold 78. In some embodiments, the material feed system may include components located outside the housing structure 62 and components located inside of the housing structure 62, or may reside completely within the housing structure 62. The material feed system 70 may be configured to heat a charge of metal into a molten state, or be configured to hold a charge of metal initially in a solid state within the housing structure, wherein it will be heated into a molten state. The material feed system is configured to transfer the molten metal charge into a component mold 78 located within the housing structure 62. At the time the molten metal charge is transferred to the component mold 78, the component mold 78 is typically already heated to a casting process temperature. The present disclosure is not limited to any particular material feed system 70 configuration.

[0038] The unloading station 74 is configured to include an operator access port 82 (e.g., a door) that allows an operator to remove a component mold 78. The unloading station 74 further includes a furnace port 84 that is configured to selectively provide an air pressure barrier (e.g., a door) between the unloading station 74 and the intermediate station 76. The furnace port 84 is also configured to permit transfer of a component mold 78 from the intermediate station 76 via the conveyor 66 to the unloading station 74. The access port 82 and the furnace port 84 are configured to be sufficiently air tight to allow the interior region of the unloading station 74 to be maintained in a vacuum condition (e.g., at a pressure less than atmospheric) for an acceptable period of time; e.g., at least the amount of time required to transfer the component mold 78 from the intermediate station 76 via the conveyor 66 to the unloading station 74. The unloading station 74 is in communication with the one or more vacuum devices 64 to permit the unloading station 74 to be evacuated to the vacuum condition.

[0039] In those embodiments wherein the housing

structure 62 is arcuately shaped and has a single loading and unloading station 72, 74 (e.g., any shape that begins and ends at the single loading and unloading station 72, 74), the single station may include an operator access port that allows an operator to insert and remove a component mold 78 from the station, a furnace inlet port that is configured to selectively provide an air pressure barrier between the single station 74 and the intermediate station 76 (through which the conveyor may transit component molds 78 into the intermediate station 76), and a furnace exit port that is configured to selectively provide an air pressure barrier between the single station 74 and the intermediate station 76 (through which the conveyor may transit component molds 78 from the intermediate station 76 and into the single station). As stated above, in such embodiments, the single loading/unloading station would have the functionality described below for loading station 72 as well as the unloading station 74.

[0040] The at least one intermediate station 76 has a length 86, a width 88, and a height 90. Within the intermediate station 76, the housing structure 62 may be described as having a base 92, a ceiling 94, a first widthwise wall 96, and a second widthwise wall 98. The height 90 may be described as extending along a vertical axis (e.g., a gravitational axis), between the base 92 and the ceiling 94. The width 88 may be orthogonal to the length 86 and the height 90, extending between the first widthwise wall 96 and the second widthwise wall 98. The length 86 extends from the loading station 72 to the unloading station 74. The diagrammatic views of the housing structure 62 depict the intermediate station 76 as having a rectangular cross-section. The intermediate station 76 is not limited to a configuration having a rectangular shaped cross-section. The height 90 and the width 88 are configured to allow a component mold 78 to transit within the intermediate station 76 from the loading station 72 end to the unloading station 74 end. As will be described below, the conveyor 66 runs in a lengthwise direction through the intermediate station 76. Hereinafter, component molds 78 transiting through the intermediate station 76 may be described in terms of "upstream" and "downstream". If, for example, there is a first component mold 78 and a second component mold 78 disposed within the intermediate station 76, and the first component mold 78 is closer to the unloading station 74 than the second component mold 78, then the first component mold 78 may be described as being "downstream" of the second component mold 78. Conversely, the second component mold 78 may be described as being "upstream" of the first component mold 78. The intermediate station 76 is configured to be sufficiently air tight to allow the interior region of the intermediate station 76 to be maintained in a vacuum condition (e.g., at a pressure less than atmospheric) for an acceptable period of time. In some embodiments, the intermediate station 76 is in communication with the one or more vacuum devices 64 to permit the intermediate station 76 to be evacuated to the vacuum condition.

[0041] The one or more heating elements 68 are dis-

posed within the intermediate station 76. In some embodiments, the one or more heating elements 68 may be disposed adjacent the first widthwise wall 96 and adjacent the second widthwise wall 98.

[0042] The one or more heating elements 68 are arranged within the intermediate station 76 so that the vertical height of a component mold 78 is progressively subjected to a different heating exposure as the component mold 78 transits through the intermediate station 76 in the direction from the loading station 72 to the unloading station 74. Referring to FIG. 3, the one or more heating elements 68 may be configured within the housing structure 62 (e.g., within the intermediate station 76) to have a first end 73 disposed adjacent the first end of the housing structure 62 (i.e., adjacent the loading station 72) and a second end 75 adjacent the second end of the housing structure (i.e., adjacent the unloading station 74), wherein the one or more heating elements are configured to provide a vertically tapered heating exposure in a direction from the first end of the housing structure 62 to the second end of the housing structure 62. In some embodiments (e.g., see FIG. 3), the one or more heating elements 68 may all extend from a position adjacent the ceiling 94 of the housing, and the vertical length of the one or more heating element 68 decreases from the first end 73 of the heating elements to the second end 75 of the heating elements 68.

[0043] The progressively changing heating exposure may be continuous or stepped. The term "continuous" refers to a heating exposure that constantly changes in the direction from the loading station 72 to the unloading station 74. The term "stepped" refers to a heating exposure that has discrete levels of heating exposure in the direction from the loading station 72 to the unloading station 74. The present disclosure is not limited to either, and in some embodiments may include sections of continuous change and sections of stepped change. As an example of a continuously changing heating element configuration (e.g., see FIG. 8), in the direction from the loading station 72 to the unloading station 74, the heating exposure may be configured to change at a linear rate; e.g., X% of the vertical height of the component mold 78 / unit transit distance within the intermediate station 76 (e.g., see also FIG. 6). Alternatively, the change may be nonlinear (e.g., see FIG. 7) wherein there is a rate of change per unit distance (i.e., non-constant, but the rate of change may vary at one or more positions between the loading station 72 and the unloading station 74).

[0044] As an example of a stepped heating element configuration, in an initial first transit distance "T1" of the intermediate station 76, 100% of the vertical height of the component mold 78 is subjected to the one or more heating elements 68. As a result, 100% of the vertical height of the respective component mold 78 is subjected to an influx of thermal energy from the one or more heating elements 68. Within this initial first transit distance "T1" of the intermediate station 76, the heating elements 68 may be aligned with 100% of the vertical height of the

component mold 78. In a second transit distance "T2" of the intermediate station 76 immediately downstream of the first transit distance T1, the vertical top X% of the vertical height of the respective component mold 78 (where "X" is an integer less than 100) is subjected to the one or more heating elements 68. As a result, the vertical top X% of the vertical height of the respective component mold 78 is subjected to an influx of thermal energy from the one or more heating elements 68. Within this second transit distance "T2" of the intermediate station 76, the heating elements 68 may be aligned with the vertical top X% of the vertical height of the respective component mold 78. In a third transit distance T3 of the intermediate station 76 downstream of the second transit T2 (and therefore downstream of T1), the vertical top Y% of the vertical height of the respective component mold 78 (where "Y" is an integer less than "X") is subjected to the one or more heating elements 68. As a result, the vertical top Y% of the vertical height of the respective component mold 78 is subjected to an influx of thermal energy from the one or more heating elements 68. Within this third transit distance "T3" of the intermediate station 76, the heating elements 68 may be aligned with the vertical top Y% of the vertical height of the respective component mold 78. The one or more heating elements 68 are configured in similar manner in each subsequent downstream transit distance (e.g., T4, T5, T6, etc., each positioned to subject a progressively smaller percentage of the respective component mold 78 (determined from the vertical top of the component mold 78)) until the one or more heating elements 68 are not positioned to produce an influx of thermal energy at the rate delivered in the upstream transit distances, or deliver any thermal energy influx at all. To facilitate the explanation, FIG. 9 graphically illustrates 100% of the vertical height of the respective component mold 78 being subjected to an influx of thermal energy from the one or more heating elements 68 for a transit distance T1, 75% of the vertical height of the respective component mold 78 being subjected to an influx of thermal energy from the one or more heating elements 68 for a transit distance T2, 50% of the vertical height of the respective component mold 78 being subjected to an influx of thermal energy from the one or more heating elements 68 for a transit distance T3, 25% of the vertical height of the respective component mold 78 being subjected to an influx of thermal energy from the one or more heating elements 68 for a transit distance T4, and 0% of the vertical height of the respective component mold 78 being subjected to an influx of thermal energy from the one or more heating elements 68 for a transit distance T5, wherein transit distance T1 is closest to the loading station 72 end of the intermediate station 76, and T5 is closest to the unloading station 74 of the intermediate station 76. The percentages described above and shown within FIG. 9 are for explanation purposes, and the present disclosure is not limited thereto.

[0045] The present disclosure is not limited to any par-

ticular type of heating element 68. Examples of acceptable heating elements 68 include induction type heaters, or resistance type heaters or some combination thereof.

[0046] In some embodiments, the conveyor furnace system 60 may include one or more cooling elements 100 in combination with the one or more heating elements 68 (e.g., see FIG. 9). In these embodiments, the one or more heating elements 68 and the one or more cooling elements 100 are arranged within the intermediate station 76 so that the vertical height of a component mold 78 is progressively subjected to a different heating exposure as the component mold 78 transits through the intermediate station 76 in the direction from the loading station 72 to the unloading station 74. As described above, the progressively changing heating exposure may be continuous or stepped; e.g., in a continuously changing heating element configuration, the heating exposure may be configured to change at a continuous rate (e.g., linear or nonlinear), and in a stepped heating element configuration wherein the heating exposure is configured to change in discrete steps. In these embodiments wherein one or more cooling elements 100 are utilized in combination with the one or more heating elements 68, the one or more cooling elements 100 are disposed to cool the portion of the vertical height of the component mold 78 that is not subjected to an influx of thermal energy from the one or more heating elements 68. Using a stepped heating element configuration as an example (see FIG. 9), in an initial first transit distance "T1" of the intermediate station 76, 100% of the vertical height of the component mold 78 is subjected to the one or more heating elements 68, and zero percent of the component mold 78 is subjected to the one or more cooling elements 100. In a second transit distance "T2" of the intermediate station 76 immediately downstream of the first transit distance T1, the vertical top 75% of the vertical height of the respective component mold 78 is subjected to the one or more heating elements 68, and the vertical lower 25% of the vertical height of the respective component mold 78 is subjected to the one or more cooling elements 100. In a third transit distance T3 of the intermediate station 76 downstream of the second transit distance T2, the vertical top 50% of the vertical height of the respective component mold 78 is subjected to the one or more heating elements 68, and the vertical lower 50% of the vertical height of the respective component mold 78 is subjected to the one or more cooling elements 100. In a fourth transit distance T4 of the intermediate station 76 downstream of the third transit distance T3, the vertical top 25% of the vertical height of the respective component mold 78 is subjected to the one or more heating elements 68, and the vertical lower 75% of the vertical height of the respective component mold 78 is subjected to the one or more cooling elements 100. In a fifth transit distance T5 of the intermediate station 76 downstream of the fourth transit distance T4, none (e.g., 0%) of the vertical height of the respective component mold 78 is subjected to the one or more heating elements 68, and

all (e.g., 100%) of the vertical height of the respective component mold 78 is subjected to the one or more cooling elements 100. The above description is provided for explanatory purposes only, and the present disclosure is not limited to the exemplary percentages and transit distances. The similar configuration could be used for a conveyor furnace system 60 having one or more cooling elements 100 in combination with the one or more heating elements 68, wherein the progressively changing heating exposure is continuous; e.g., the portion of the vertical height of the respective component mold 78 not subjected to the one or more heating elements 68 may be subjected to the one or more cooling elements 100.

[0047] Referring to FIG. 10, in some embodiments, the housing structure 62 may include a plurality of thermal separators 102 disposed within the intermediate station 76. For example, in those embodiments having a stepped heating element 68 configuration, a thermal separator 102 may be disclosed between each thermal zone. Using the example provided above and diagrammatically shown in FIG. 10, a first thermal separator 102 may be disposed at the lengthwise point within the intermediate station 76 aligned with the end of the first transit distance "T1" and the beginning of the second transit distance "T2", and a second thermal separator 102 may be disposed at the lengthwise point aligned with the end of the second transit distance "T2" and the beginning of the third transit distance "T3". FIG. 10 illustrates the likewise positioning of a third, fourth, and fifth thermal separator 102. The present disclosure is not, however, limited to vertically-oriented thermal separators 102, however. For example, in an alternative embodiment (e.g., see FIG. 11), a plurality of thermal separators 102 can be disposed to extend generally lengthwise, but skewed at an angle relative to the travel direction of the component molds 78; e.g., oriented to extend generally along a line coincident with the vertically lowest segment of the heating elements 68 disposed within the intermediate station 76. A non-limiting example of a thermal separator 102 is a curtain of carbon elements.

[0048] A conveyor 66 is configured to transit component molds 78 within the conveyor furnace system 60; e.g., from the loading station 72, through the intermediate station 76, to the unloading station 74. In some embodiments, the conveyor furnace system 60 may be configured in a linear (i.e., substantially straight) arrangement; e.g., the loading station 72 and the unloading station 74 are disposed at opposite ends of the intermediate station 76, and the loading station 72, intermediate station 76, and unloading station 74 are in line with one another. In this configuration, the conveyor 66 is configured to transit component molds 78 from the loading station 72, through the intermediate station 76, to the unloading station 74. The present disclosure is not limited to any particular type of conveyor 66. An example of an acceptable conveyor is a "walking bridge" type conveyor. If a walking bridge type conveyor is used, each component mold 78 may be connected to a copper block that is configured to traverse

along the walking conveyor. Elements of the walking bridge may be cooled to further heat transfer from the component molds via the copper blocks. An alternative type conveyor 66 may include structure for pushing the component molds 78 (and copper blocks if attached) individually or collectively through the housing structure 62. As a further alternative, the conveyor 66 may be configured in a closed loop; e.g., where the conveyor 66 circles through the housing structure 62. The present disclosure is not, however, limited to a conveyor furnace system 60 having a linear configuration. In another non-limiting example, the conveyor furnace system 60 may have an arcuate configuration; e.g., an oval configuration, a circular configuration (see FIG. 5), etc. In any of the conveyor 66 embodiments, the conveyor 66 may be configured to rotate the component molds 78 as they traverse through the intermediate station 76 to improve the transfer of thermal energy to and from the component molds 78. In some embodiments, the conveyor 66 may be configured to alter the vertical position of each component mold 78 as it progresses through the intermediate station 76; e.g., progressively drop the vertical position of the component mold as it traverses through the intermediate station 76. Changing the vertical position of a component mold 78 may be used as a means to alter the relative positions of the component mold 78 and the respective heating element 68, and thereby change the portion of the component mold being subjected to an influx of thermal energy from the one or more heating elements 68 or subjected to cooling element 100.

[0049] In some embodiments, the one or more vacuum devices 64 may be a single vacuum pump system with valving that permits evacuation of different zones and subsequent maintenance of a vacuum condition (e.g., an air pressure lower than ambient). In this configuration, the loading station 72 may be a first zone, the intermediate station 76 a second zone, and the unloading station 74 a third zone, with the atmospheric pressure in each zone independently controllable. In an alternative embodiment, the one or more vacuum devices 64 may include a vacuum pump system for each zone that permits evacuation of the respective zone and subsequent maintenance of a vacuum condition (e.g., an air pressure lower than ambient) within that respective zone. In some embodiments, the conveyor furnace system 60 may include a source of inert gas that is configured to provide inert gas into the intermediate station 76; e.g., directed onto defined sections of a component mold 78 for cooling or other purposes.

[0050] The conveyor furnace system 60 may include a control system 104 configured to permit an operator to control operation of the conveyor furnace system 60. The control system 104 may be in communication (e.g., signal communication) with one or more of the one or more heating elements 68, the conveyor 66, the one or more vacuum devices 64, the material feed system 70, the loading station 72, the unloading station 74, sensors 106 (e.g., temperature sensors, pressure sensors, etc.), and

other aspects of the conveyor furnace system 60. The control system 104 may include any type of computing device, computational circuit, or any type of process or processing circuit capable of executing a series of instructions that are stored in memory. The controller may include multiple processors and/or multicore CPUs and may include any type of processor, such as a microprocessor, digital signal processor, co-processors, a microcontroller, a microcomputer, a central processing unit, a field programmable gate array, a programmable logic device, a state machine, logic circuitry, analog circuitry, digital circuitry, etc., and any combination thereof. The instructions stored in memory may represent one or more algorithms for controlling the aspects of the conveyor furnace system 60 (e.g., the heating elements 68, the vacuum devices 64, the conveyor 66, etc.), and the stored instructions are not limited to any particular form (e.g., program files, system data, buffers, drivers, utilities, system programs, etc.) provided they can be executed by the controller. The memory may be a non-transitory computer readable storage medium configured to store instructions that when executed by one or more processors, cause the one or more processors to perform or cause the performance of certain functions. The memory may be a single memory device or a plurality of memory devices. A memory device may include a storage area network, network attached storage, as well as a disk drive, a read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, cache memory, and/or any device that stores digital information. One skilled in the art will appreciate, based on a review of this disclosure, that the implementation of the control system 104 may be achieved via the use of hardware, software, firmware, or any combination thereof. The control system 104 may also include input (e.g., a keyboard, a touch screen, etc.) and output devices (a monitor, sensor readouts, data ports, etc.) that enable the operator to input instructions, receive data, etc.

[0051] The following non-limiting method is an example of how the present disclosure may be implemented to produce a directionally solidified component. The operator may insert at least one empty component mold 78 within the loading station 72, and engage the same with the conveyor 66. The access port 82 and furnace port 80 of the loading station 72 are closed to segregate the loading station 72. The one or more vacuum devices 64 are operated (e.g., via operator input and instructions from the control system 104) to evacuate the loading station 72. In some embodiments, one or more heating elements 68 may be disposed in the loading station 72. In these embodiments, the one or more heating elements 68 may be controlled (e.g., via operator input and/or instructions from the control system 104) to heat the component mold 78 up to a predetermined temperature (e.g., a casting process temperature) prior to the component mold being transferred to the intermediate station 76. At the same time, or prior thereto, the one or more heating elements

68 disposed within the intermediate station 76 are operated (e.g., via operator input and/or instructions from the control system 104) to raise the temperature within the sections of the intermediate station 76 to a predetermined temperature. In those embodiments that include one or more cooling elements 100, the one or more cooling elements 100 may also be operated (e.g., via operator input and/or instructions from the control system 104) to produce a region of lower temperature relative to the higher temperature regions associated with the one or more heating elements 68. The one or more vacuum devices 64 are operated (e.g., via operator input and instructions from the control system 104) to evacuate the intermediate station 76. Once the heating elements 68 are at the requisite temperature and the intermediate station 76 is evacuated, the furnace port 80 of the loading station 72 may be opened (e.g., via operator input and/or instructions from the control system 104) and the conveyor 66 activated to transfer the empty component mold 78 from the loading station 72 to the intermediate station 76. As indicated above, the material feed system 70 is configured to transfer a charge of molten metal sufficient to fill a component mold 78. The transfer of molten metal may occur within the loading station 72 or initially within the intermediate station 76. The present disclosure is not limited to any particular material feed system 70 configuration.

[0052] The conveyor 66 may be controlled to transit the now filled component mold 78 through the intermediate station 76 in the direction from the loading station 72 end towards the unloading station 72 end. The conveyor 66 may transit the filled component mold 78 through the intermediate station 76 at a constant or a variable rate, or in a step function manner, or some combination thereof. As the filled component mold 78 transits through the intermediate station 76, initially 100% of the vertical height of the component mold 78 is subjected to the thermal energy from the one or more heating elements 68; e.g., located on both widthwise sides of the intermediate station 76. In those embodiments that include one or more cooling elements 100, initially none of the vertical height of filled component mold 78 is subjected to the one or more cooling elements 100. As the filled component mold 78 continues its transit through the intermediate station 76, an increasingly lesser portion of the filled component mold 78 (from the vertical top end) is subjected to thermal energy from the one or more heating elements 68. During this same phase of the transit through the intermediate station 76, in those embodiments that include one or more cooling elements 100, an increasingly greater portion of the filled component mold 78 (from the vertical bottom end) is subjected to the one or more cooling elements 100. As the filled component mold 78 approaches the unloading station 74 end of the intermediate station 76, none of the vertical height of filled component mold 78 is subjected to thermal energy from the one or more heating elements 68. During this same phase, in those embodiments that include one

or more cooling elements 100, 100% of the filled component mold 78 is subjected to the one or more cooling elements 100.

[0053] As the filled component mold 78 approaches the unloading station 74, or prior thereto, the access port 82 and furnace port 84 of the unloading station 74 may be closed to segregate the unloading station 74, and the one or more vacuum devices 64 are operated (e.g., via operator input and instructions from the control system 104) to evacuate the unloading station 74. Once the unloading station 74 is evacuated, the furnace port 84 of the unloading station 74 may be opened (e.g., via operator input and/or instructions from the control system 104) and the conveyor 66 activated to transfer the filled component mold 78 from the intermediate station 76 to the unloading station 74. The furnace port 84 of the unloading station 74 is subsequently closed, and the one or more vacuum devices 64 (or other valving) are operated to return the unloading station 74 to an ambient pressure. The filled component mold 78 may then be removed from the unloading station 74 via the access door 82.

[0054] As stated above, in some embodiments, the conveyor furnace system 60 may have a circular housing structure 62 that utilizes a single structure that is configured to function as both the loading and unloading stations 72, 74. In such embodiments, the process described above may remain essentially as described above, with the combined loading/unloading station performing the described functions associated with loading empty component molds 78 and unloading filled and processed component molds 78.

[0055] While various embodiments of the present disclosure have been disclosed, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible within the scope of the present disclosure. For example, the present disclosure as described herein includes several aspects and embodiments that include particular features. Although these features may be described individually, it is within the scope of the present disclosure that some or all of these features may be combined with any one of the aspects and remain within the scope of the present disclosure. Accordingly, the present disclosure is not to be restricted except in light of the attached claims.

Claims

1. A conveyor furnace system, comprising:

a housing (62) having a first end and a second end, the second end opposite the first end;
a conveyor (66) configured to transit one or more component molds (78) from the first end to the second end, each component mold (78) having a base end (108) and a top end (110) and a height extending therebetween;
a vacuum device (64) configured to selectively

produce a below atmospheric pressure within the housing (62); and

a plurality of heating elements (68) disposed in the housing (62), the plurality of heating elements (68) is arranged within the housing (62) so that the one or more component molds (78) transiting through the housing (62) are subjected to a progressively different heating exposure in a direction from the first end to the second end during operation of the system.

2. The system of claim 1, wherein the housing (62) includes a loading station (72) and an intermediate station (76), and the conveyor (66) is configured to transit the one or more component molds (78) from the loading station (72) and into the intermediate station (76), and the plurality of heating elements (68) are disposed in the intermediate station (76).

3. The system of claim 2, wherein the housing (62) includes an unloading station (74), and the loading station (72) is disposed at the first end of the housing (62), and the unloading station (74) is disposed at the second end of the housing (62), and the intermediate station (76) is disposed between the first end and the second end.

4. The system of claim 3, wherein:

the loading station (72), the intermediate station (76), and the unloading station (74) are linearly arranged; or

the loading station (72), the intermediate station (76), and the unloading station (74) are non-linearly arranged.

5. The system of claim 3 or 4, wherein the vacuum device (64) is configured to selectively produce a below atmospheric pressure within the loading station (72), the unloading station (74), and the intermediate station (76), all independent from one another.

6. The system of claim 1, wherein the housing (62) includes at least one station (72, 74) configured for loading and unloading component molds (78).

7. The system of claim 6, wherein the housing (62) includes an intermediate station (76) that extends arcuately from the at least one station (72, 74), and the first end of the housing (62) is disposed at the at least one station (72, 74) and the second end of the housing (62) is disposed at the at least one station (72, 74).

8. The system of any preceding claim, wherein:

the progressively different heating exposure continuously changes in the direction from the

- first end to the second end during operation of the system, wherein, optionally, the progressively different heating exposure continuously decreases in the direction from the first end to the second end during operation of the system; or
the progressively different heating exposure changes in a stepped configuration in the direction from the first end to the second end during operation of the system, wherein, optionally, the stepped configuration includes a plurality of steps, with each downstream step having a decreased heating exposure.
9. The system of any preceding claim, further comprising a plurality of cooling elements (100), and the plurality of cooling elements (100) is arranged within the housing (62) relative to the plurality of heating elements (68) so that the one or more component molds (78) transiting through the housing (62) are subjected to a progressively different heating exposure in a direction from the first end to the second end during operation of the system.
10. A conveyor furnace system, comprising:
a housing (62) having a first end and a second end, the second end opposite the first end;
a conveyor (66) configured to transit one or more component molds (78) from the first end to the second end, each component mold (78) having a base end (108) and a top end (110) and a height extending therebetween;
a vacuum device (64) configured to selectively produce a below atmospheric pressure within the housing (62); and
at least one heating element (68) disposed in the housing (62), the at least one heating element (68) has a first end (73) disposed adjacent the first end of the housing (62) and a second end (75) adjacent the second end of the housing (62), wherein the at least one heating element (68) is configured to provide a vertically tapered heating exposure in a direction from the first end of the housing (62) to the second end of the housing (62).
11. The system of claim 10, wherein the first end (73) of the heating element (68) has a first vertical heating exposure portion, and the second end (75) of the heating element (68) having a second vertical heating exposure portion, and the first vertical heating exposure portion is greater than the second vertical heating exposure portion, wherein, optionally, the first vertical heating exposure portion and the second vertical heating exposure portion both extend from adjacent a ceiling (94) of the housing (62).
12. A method of producing a directionally solidified component, comprising:
heating a component mold (78) within a conveyor furnace system (60) to a predetermined temperature, the conveyor furnace system (60) having a housing (62) with a first lengthwise end and an opposite second lengthwise end, and the component mold (78) having a top vertical end (110) and a bottom vertical end (108);
transferring a charge of molten metal into the heated component mold (78);
transiting the heated component mold (78) containing the charge of molten metal within the housing (62) from the first lengthwise end to the second lengthwise end; and
exposing the heated component mold (78) containing the charge of molten metal to a vertically tapered heating exposure in a direction from the first lengthwise end of the housing (62) to the second lengthwise end of the housing (62).
13. The method of claim 12, further comprising selectively creating an environment within the housing (62) that is below atmospheric pressure.
14. The method of claim 12 or 13, wherein the housing includes a loading station (72) disposed at the first lengthwise end of the housing (62) and an unloading station (74) disposed at the second lengthwise end of the housing (62), and an intermediate station (76) disposed between the loading station (72) and the unloading station (74);
the method further comprising loading the component mold (78) into the loading station (72) prior to heating the component mold (78) to the predetermined temperature, transiting the component mold (78) from the loading station (72), through the intermediate station (76), and into the unloading station (74), and unloading the component mold (78) from the unloading station (74).
15. The method of claim 14, further comprising selectively creating an environment within the loading station (72) that is below atmospheric pressure prior to transiting the component mold (78) from the loading station, through the intermediate station (76), and into the unloading station (74).

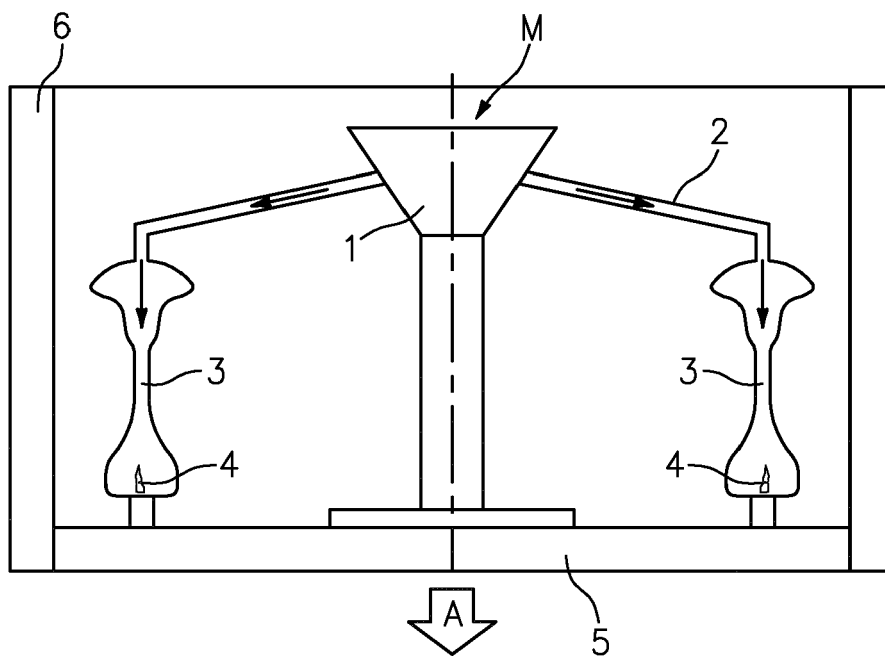


FIG. 1
(PRIOR ART)

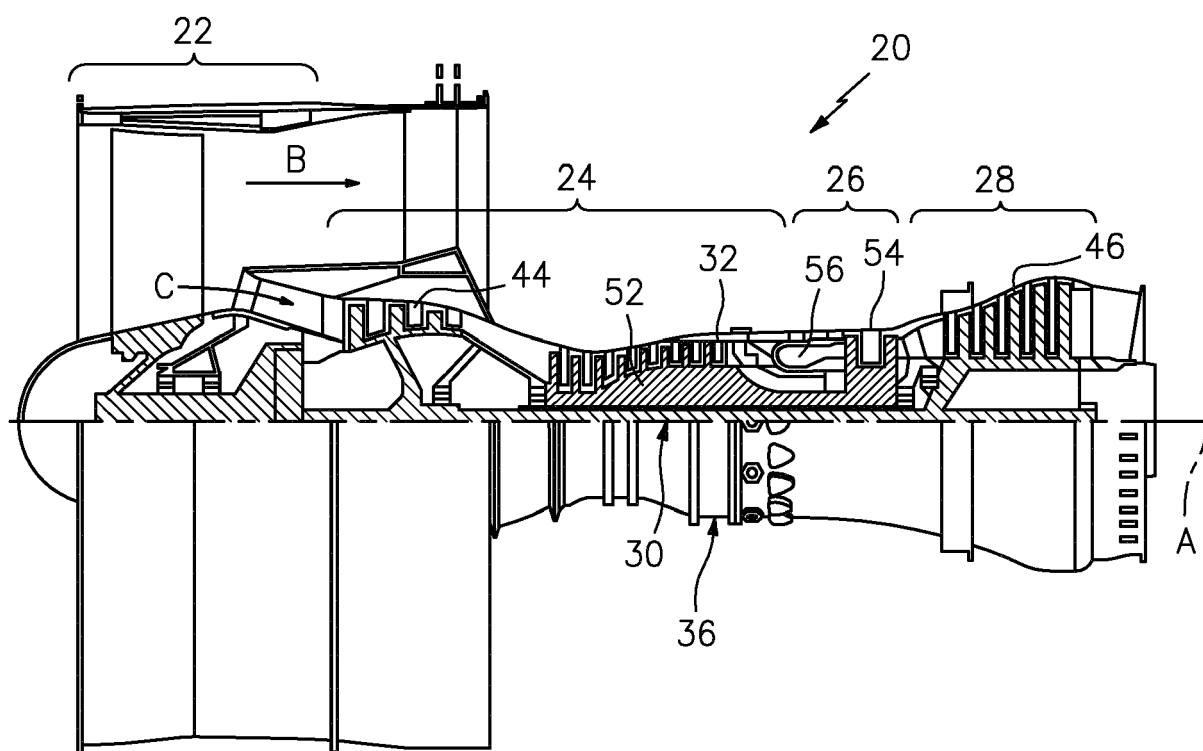


FIG. 2

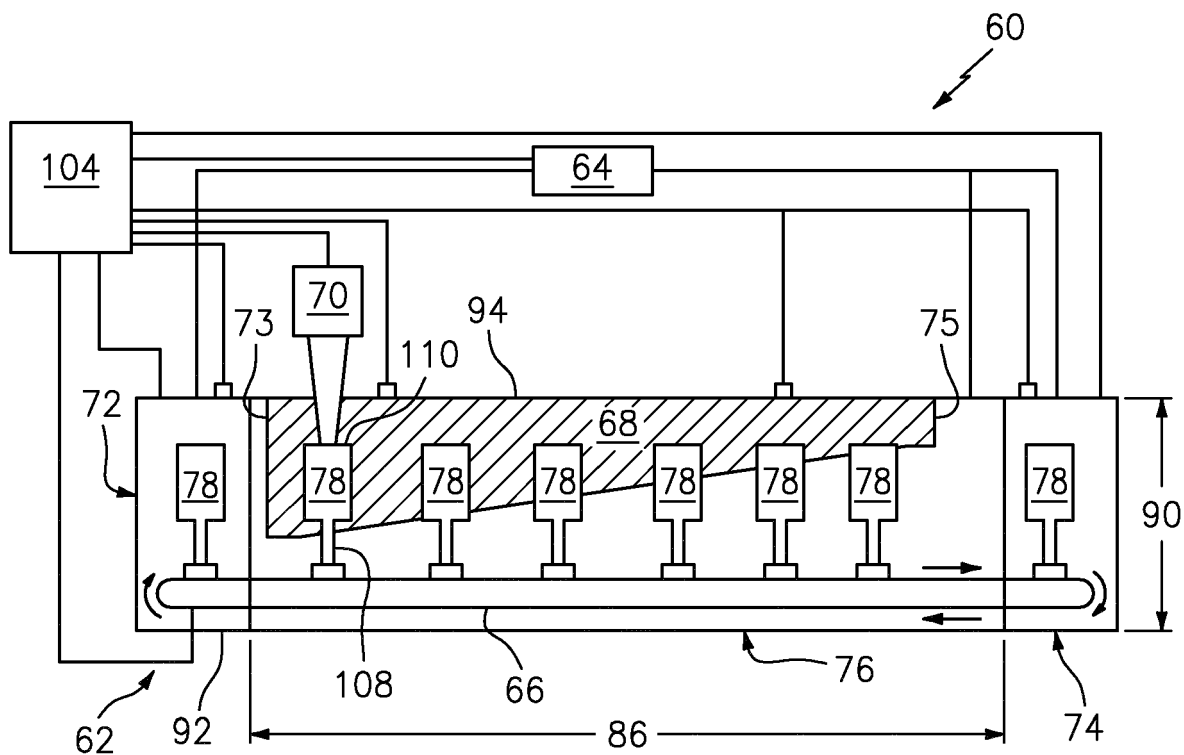


FIG. 3

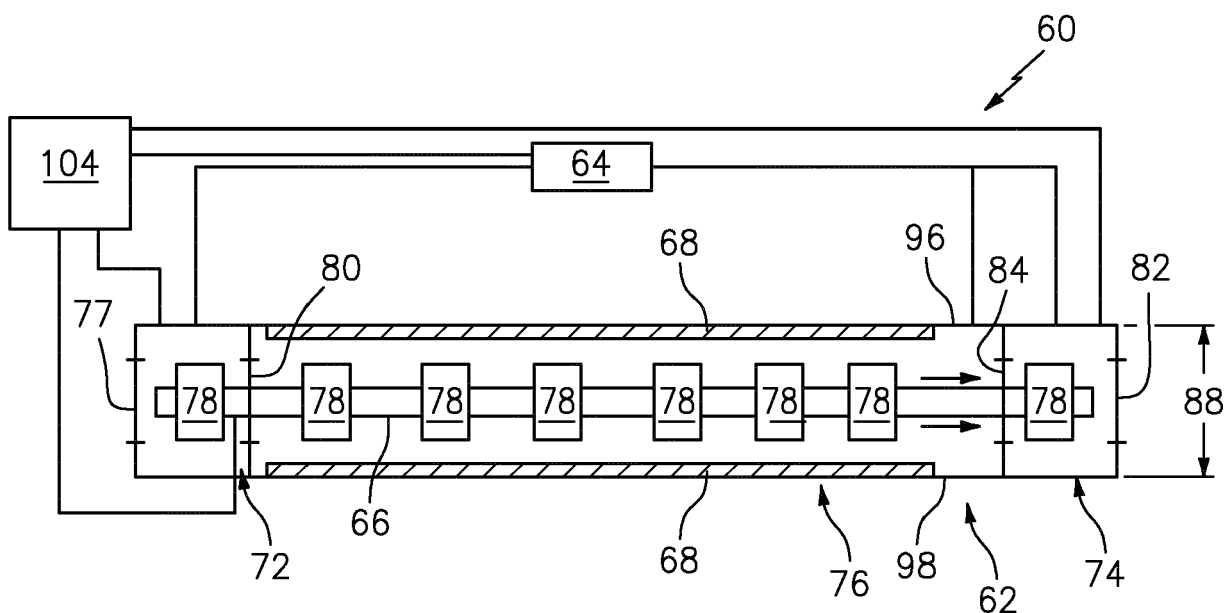


FIG. 4

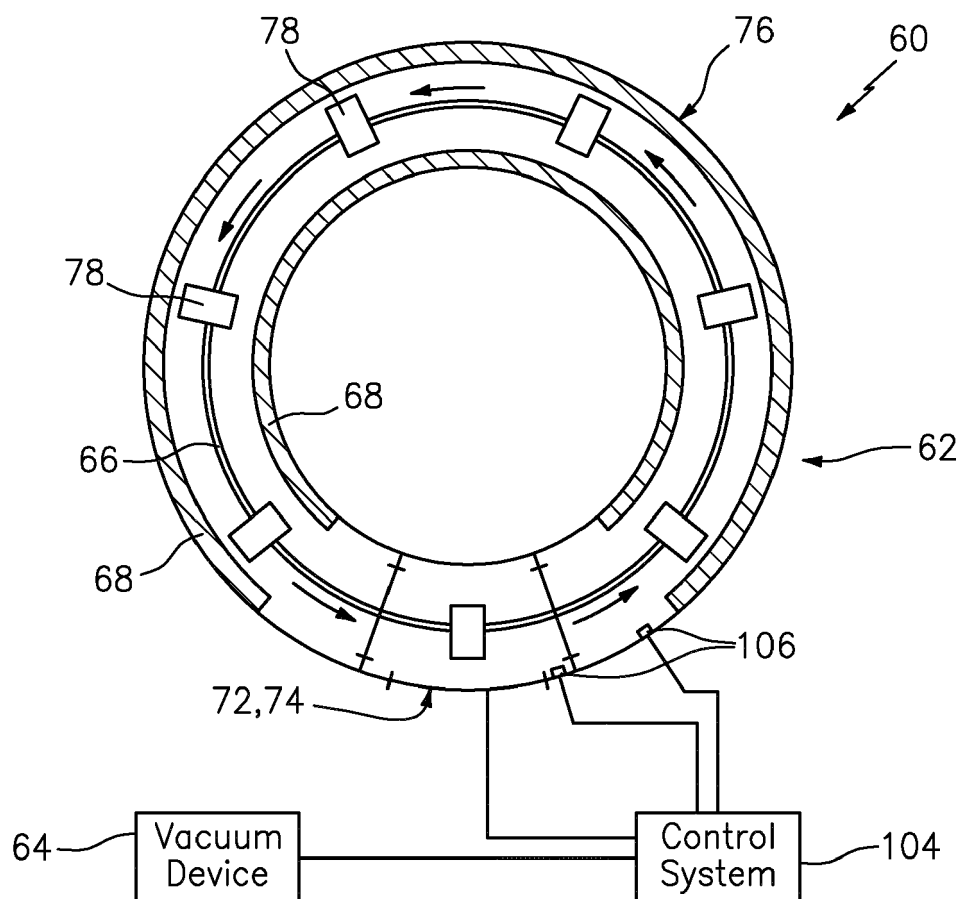


FIG. 5

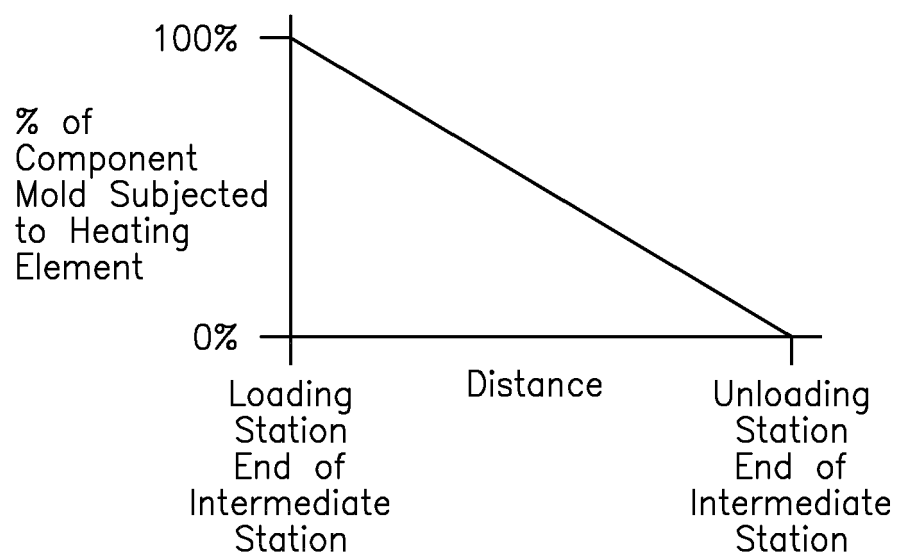


FIG. 6

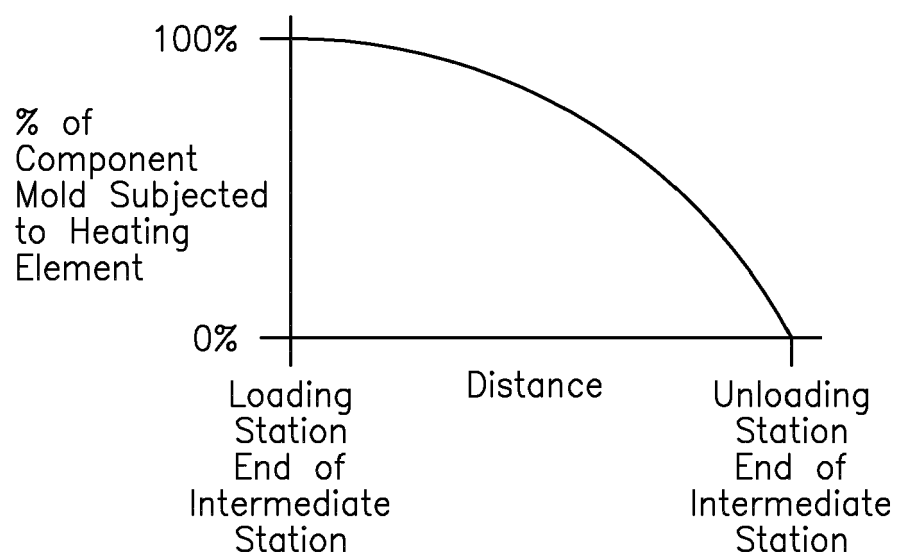
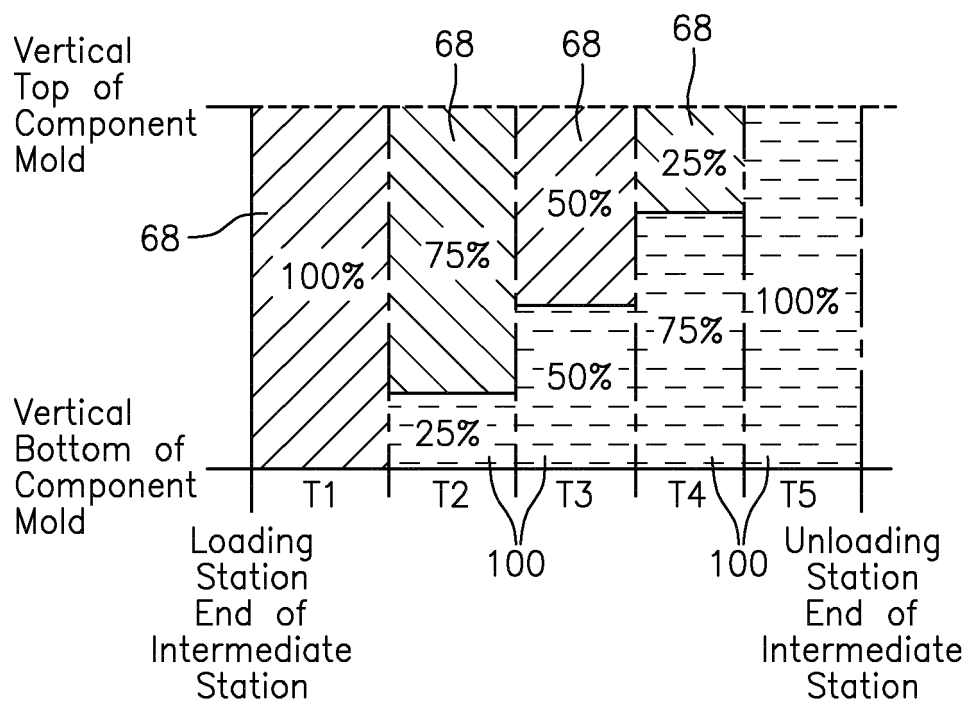
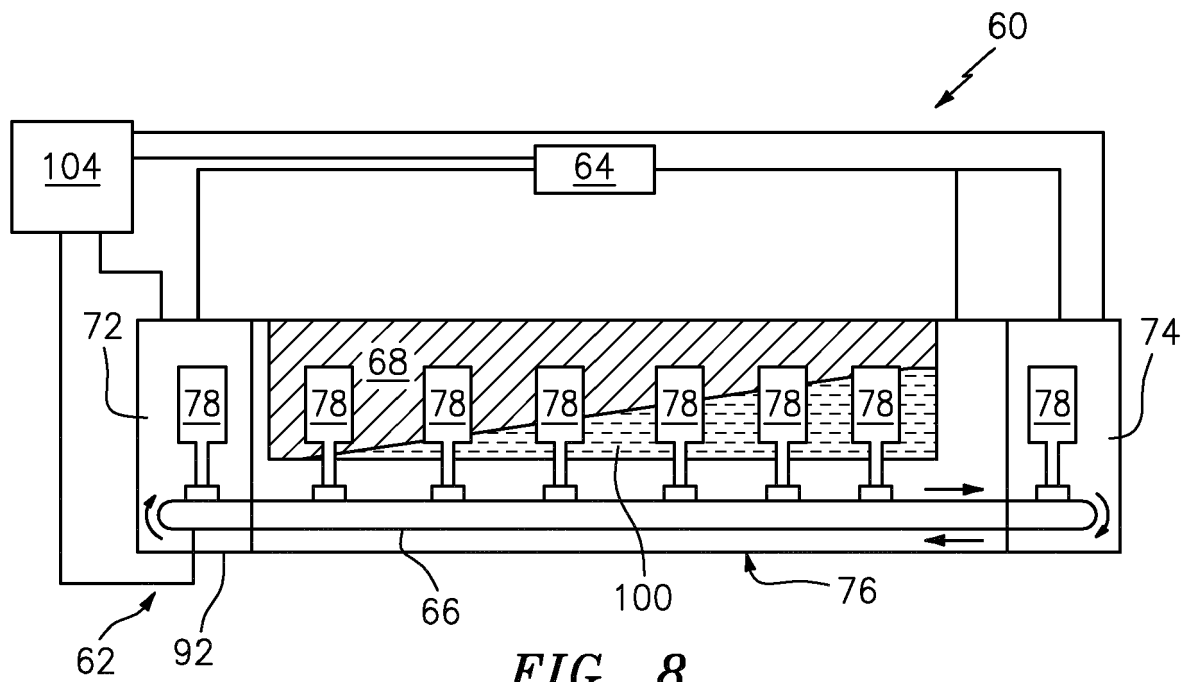


FIG. 7



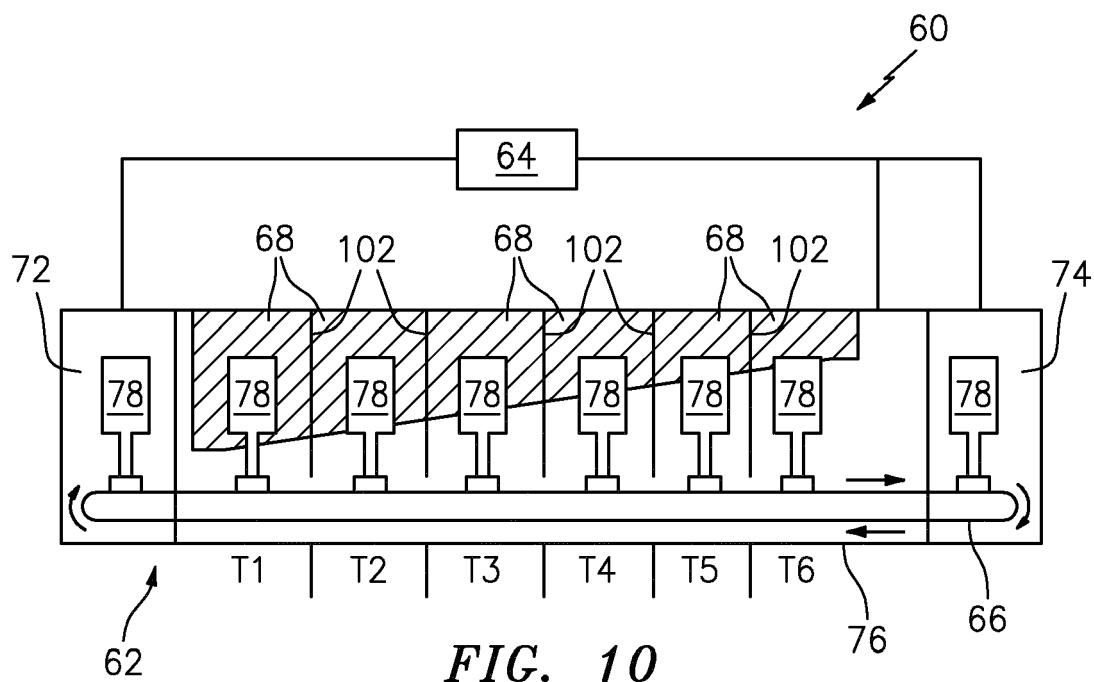


FIG. 10

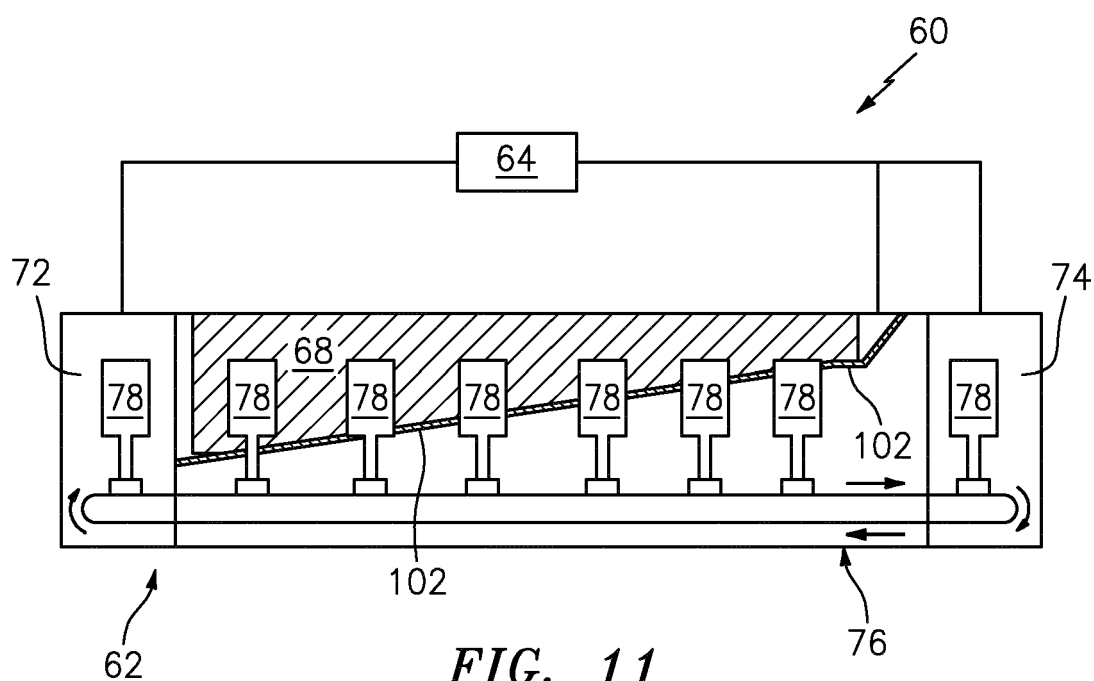


FIG. 11



EUROPEAN SEARCH REPORT

Application Number
EP 19 19 7378

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 11 February 2020	Examiner Scheid, Michael
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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ON EUROPEAN PATENT APPLICATION NO.**

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