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(54) SEGMENTED HEAT EXCHANGER

(57) A method can comprise dividing a heat exchanger design into a plurality of modules (10), the plurality of modules (10) arranged in a grid, each module in the plurality of modules (10) including: a first fluid conduit (161) defining an inlet (1611), an outlet (1612), and a heat-transfer surface (602), and a first flow direction, and a second fluid conduit (162) defining a second inlet, a second outlet, a second heat-transfer surface, and a second flow direction, the second flow direction different from the first flow direction; and determining a heat-transfer augmenter arrangement (1161) for the first fluid conduit (161) and the second fluid conduit (162) of each module in the plurality of modules (10) based on a stress threshold of the module (16) in the plurality of modules (10).

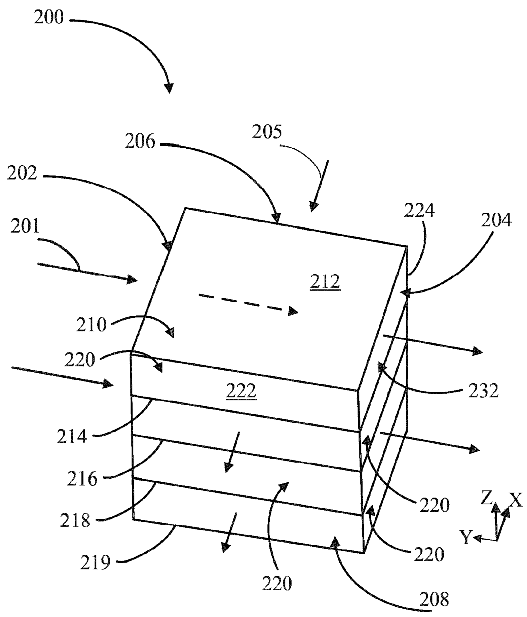

FIG. 2

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to heat exchangers and methods of design, and, more specifically, to a segmented heat exchanger with variable heat-transfer properties for each segment.

BACKGROUND

[0002] As heat is transferred through a heat exchanger, material of the heat exchanger experiences thermal structural fatigue due to the temperature difference between a hot side and a cold side of the heat exchanger. This temperature difference is largest at a corner of the heat exchanger where hot air and cold air both enter. To prevent structure fatigue, the temperature differences throughout the heat exchanger are kept below the maximum stress limit the material can endure before yielding. However, constraining the temperature difference also limits the maximum total heat that can be transferred through the heat exchanger.

SUMMARY

[0003] A method is disclosed herein. In various embodiments, the method comprises: dividing a heat exchanger design into a plurality of modules, the plurality of modules arranged in a grid, each module in the plurality of modules including: a first fluid conduit defining an inlet, an outlet, and a heat-transfer surface, and a first flow direction, and a second fluid conduit defining a second inlet, a second outlet, a second heat-transfer surface, and a second flow direction, the second flow direction different from the first flow direction; and determining a heat-transfer augmenter arrangement for the first fluid conduit and the second fluid conduit of each module in the plurality of modules based on a stress threshold of the module in the plurality of modules.

[0004] In various embodiments, the method further comprises manufacturing a heat exchanger based on the heat exchanger design.

[0005] In various embodiments, the first fluid conduit of each module in the plurality of modules forms a first heat exchanger fluid conduit extending from a first side of the heat exchanger design to a second side of the heat exchanger design, and the second fluid conduit of each module in the plurality of modules form together a second heat exchanger fluid conduit extending from a third side of the heat exchanger design to a fourth side of the heat exchanger design. In various embodiments, in response to determining the heat-transfer augmenter arrangement, the first fluid conduit in a first module of the plurality of modules has a first heat-transfer coefficient and the first fluid conduit in a second module of the plurality of modules has a second heat-transfer coefficient, the second heat-transfer coefficient being different than the first heat-transfer coefficient. In various embodiments, in response to determining the heat-transfer augmenter arrangement, the first fluid conduit in a first module of the plurality of modules includes a first wave and the first fluid conduit in the second module of the plurality of modules has a second wave, the second wave having a different wavelength than the first wave. In various embodiments, the first fluid conduit is disposed vertically adjacent to the second fluid conduit.

[0006] In various embodiments, the determining the heat-transfer augmenter arrangement further comprises simulating each module in the plurality of modules as an independent heat exchanger in the heat exchanger design.

[0007] In various embodiments, the heat exchanger design is a plate heat exchanger design.

[0008] A design process is disclosed herien. In various embodiments, the design process comprises: receiving, via a processor, boundary conditions for designing a modular heat exchanger, the modular heat exchanger comprising an M x N grid of modules, each module including at least two of a first fluid conduit defining a first flow direction interleaved and at least two off a second fluid conduit defining a second flow direction, the at least two of the first fluid conduit interleaved between the at least two of the second fluid conduit, the boundary conditions including a stress threshold envelope; determining, via the processor and through a simulator, a desired heat-transfer coefficient for each heat-transfer surface in each fluid conduit of the modular heat exchanger based on the boundary conditions; and in response to determining the desired heat-transfer coefficient, designing a heat-transfer arrangement for each fluid conduit in each module of the modular heat exchanger.

[0009] In various embodiments, the boundary conditions further include an inlet temperature of a first fluid at a first side of the modular heat exchanger and a second inlet temperature of a second fluid at a second side of the modular heat exchanger.

[0010] In various embodiments, M x N is at least 3 x 3.

[0011] In various embodiments, the first fluid conduit of each module in the plurality of modules forms a first heat exchanger fluid conduit extending from a first side of the modular heat exchanger to a second side of the modular heat exchanger, and the second fluid conduit of each module in the plurality of modules form together a second heat exchanger fluid conduit extending from a third side of the modular heat exchanger to a fourth side of the modular heat exchanger. In various embodiments, the designing the heat-transfer arrangement includes designing a first wave in the first fluid conduit of a first module and designing a second wave in the first fluid conduit of a second module, the first wave having a different wavelength than the second wave. In various embodiments, the designing the heat-transfer arrangement includes designing a first heat-transfer augmenter in the first fluid conduit of the first module and designing a second heat-transfer augmenter in the first fluid conduit of the second module, wherein the first heat-transfer augmenter is different from the second heat-transfer augmenter. A modular heat exchanger is disclosed herein. In various embodiments, the modular heat exchanger comprises: a grid of heat exchanger modules, the grid of heat exchanger modules comprising: a first side disposed laterally opposite a second side, a first plurality of fluid conduits, each fluid conduit in the first plurality of fluid conduits extending from the first side to the second side, each fluid conduit in the first plurality of fluid conduits extending through a first set of modules in the grid of heat exchanger modules, a first fluid conduit of a first module in the grid of heat exchanger modules, a second fluid conduit of a second module in the grid of heat exchanger modules, and a third fluid conduit of a third module in the grid of heat exchanger modules defining a respective fluid conduit in the first plurality of fluid conduits, and a first heat-transfer arrangement of a first heat-transfer surface in the first fluid conduit being different from a second heat-transfer arrangement of a second heat-transfer surface of the second fluid conduit.

[0012] In various embodiments, a third heat-transfer arrangement of a third heat-transfer surface of the third fluid conduit is different from the first heat-transfer arrangement and the second heat-transfer arrangement.

[0013] In various embodiments, the grid of heat exchanger modules further comprises a third side disposed laterally opposite a fourth side, a second plurality of fluid conduits extending from the third side to the fourth side, each fluid conduit in the second plurality of fluid conduits extending through a second set of modules in the grid of heat exchanger modules. In various embodiments, a fourth fluid conduit of a fourth module in the grid of heat exchanger modules, a fifth fluid conduit of a fifth module in the grid of heat exchanger modules, and the first module in the grid of heat exchanger modules defines a sixth fluid conduit in the second plurality of fluid conduits. In various embodiments, a fourth heat-transfer arrangement of a fourth heat-transfer surface in the fourth fluid conduit is different from a fifth heat-transfer arrangement of a fifth heat-transfer surface of the fifth fluid conduit. In various embodiments, a sixth heat-transfer arrangement of a sixth heat-transfer surface of the sixth fluid conduit is different from the fourth heat-transfer arrangement and the fifth heat-transfer arrangement.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The subject matter of the present disclosure is particularly pointed out and distinctly claimed in the concluding portion of the specification. A more complete understanding of the present disclosure, however, may best be obtained by referring to the following detailed description and claims in connection with the following drawings. While the drawings illustrate various embodiments employing the principles described herein, the drawings do not limit the scope of the claims.

FIG. 1 illustrates a cross-sectional view of a gas turbine engine, in accordance with various embodiments.

FIG. 2 illustrates a perspective view of a heat exchanger, in accordance with various embodiments.

FIG. 3 illustrates a method of designing and manufacturing a heat exchanger, in accordance with various embodiments.

FIG. 4A illustrates a top down view of a heat exchanger design, in accordance with various embodiments.

FIG. 4B illustrates a cross-sectional view along section line A-A from FIG. 4A, in accordance with various embodiments.

FIG. 4C illustrates a cross-sectional view along section line B-B from FIG. 4A, in accordance with various embodiments.

FIG. 5A illustrates a profile of a wave in a heat transfer augmenter arrangement, in accordance with various embodiments.

FIG. 5B illustrates a profile of a wave in a heat transfer augmenter arrangement, in accordance with various embodiments.

FIG. 5C illustrates a profile of a wave in a heat transfer augmenter arrangement, in accordance with various embodiments.

FIG. 6 illustrates various heat transfer augmenter configurations, in accordance with various embodiments.

FIG. 7 illustrates a design process for designing a heat exchanger, in accordance with various embodiments.

DETAILED DESCRIPTION

[0015] The following detailed description of various embodiments herein refers to the accompanying drawings, which show various embodiments by way of illustration. While these various embodiments are described in sufficient detail to enable those skilled in the art to practice the disclosure, it should be understood that other embodiments may be realized and that changes may be made without departing from the scope of the disclosure. Thus, the detailed description herein is presented for purposes of illustration only and not of limitation. Furthermore, any reference to singular includes plural embodiments, and any reference to more than one component or step may include a singular embodiment or step. Also, any reference to attached, fixed, connected, or the like may include permanent, removable, temporary, partial, full or any other possible attachment option. Additionally, any reference to without contact (or similar phrases) may also include reduced contact or minimal contact. It should also be understood that unless specifically stated otherwise, references to "a," "an" or "the" may include one or more than one and that reference to an item in the singular may also include the item in the plural. Further, all ranges may include upper and lower values and all ranges and ratio limits disclosed herein may be combined.

[0016] Typical heat exchangers are designed and configured to meet desired heat-transfer and desired pressure drop metrics. After the design is modeled, structural simulations are performed to determine whether structural criteria for the heat exchanger has been met. In response to the simulations, the heat exchanger model often goes through various design iterations and modifications to reduce a stress impact due to thermal loads throughout the heat exchanger during operation. Heat exchangers designed in this manner typically include consistent heat-transfer features throughout the heat exchanger (i.e., one section is designed and configured identical to an adjacent section) within the heat exchanger.

[0017] Disclosed herein is a heat exchanger comprising a plurality of heat exchanger modules. The plurality of heat exchanger modules can be arranged in a grid (e.g., a four x four grid, a five by five grid, a six by six grid, etc.). The present disclosure is not limited in this regard. Each module in the plurality of heat exchanger modules can have similar external parameters (i.e., can be approximately a same size and shape externally).

[0018] However, each module in the plurality of heat exchanger modules can comprise variable internal parameters (i.e., variable heat-transfer augmentors within a fluid conduit disposed therethrough). In this regard, each heat exchanger module can be designed and configured to optimize a total heat-transfer through the heat exchanger module, in accordance with various embodiments, as described further herein.

[0019] In typical heat exchanger modeling, heat exchangers are designed and sized based on a total heat-transfer threshold (e.g., a heat-transfer coefficient threshold) and pressure drop threshold (e.g., a change in pressure from an inlet to the heat exchanger to an outlet of the heat exchanger). In typical heat exchanger model, the constraints are often added afterwards, and thermal stress analysis is performed on the design to determine whether the heat exchanger meet deterministic stress criteria (i.e., as a function of material properties of the heat exchanger). The typical heat exchanger model then goes through design iterations with modifications to reduce the stress impact until the heat exchanger meets the deterministic stress criteria. Disclosed herein is a heat exchanger design process that tailors an initial heat exchanger design for heat-transfer and stress reduction to ensure that the heat exchanger design meets a deterministic-criteria for stress and heat-transfer. The design process disclosed herein allows for a more rigorous and tailored design process making the process significantly faster by reducing the number of iterations on the heat exchanger design, in accordance with various embodiments.

[0020] Referring to FIG. 1, a gas turbine engine 100 (such as a turbofan gas turbine engine) is illustrated according to various embodiments. Gas turbine engine 100 is disposed about axial centerline axis 120, which may also be referred to as axis of rotation (e.g., axial centerline axis 120). Gas turbine engine 100 may comprise a fan 140, compressor sections 150 and 160, a combustion section 180, and turbine sections 190, 191. The fan 140 may drive air into compressor sections 150, 160, which further drive air along a core flow path for compression and communication into the combustion section 180. Air compressed in the compressor sections 150, 160 may be mixed with fuel and burned in combustion section 180 and expanded across the turbine sections 190, 191. The turbine sections 190, 191 may include high pressure rotors 192 and low pressure rotors 194, which rotate in response to the expansion. The turbine sections 190, 191 may comprise alternating rows of rotary airfoils or blades 196 and static airfoils or vanes 198. Cooling air may be supplied to the turbine sections 190, 191 from the compressor sections 150, 160. A plurality of bearings 115 may support spools in the gas turbine engine 100. FIG. 1 provides a general understanding of the sections in a gas turbine engine, and is not intended to limit the disclosure. The present disclosure may extend to all types of applications and to all types of turbine engines, including turbofan engines, turboprop engines, and turbojet engines.

[0021] Multiple sections of the gas turbine engine 100 generate heat during engine operation, including the fan 140, the compressor sections 150, 160, the combustion section 180, the turbine sections 190, 191, and mechanical components such as bearings 115 and gearboxes. The heat may be carried by fluids that are communicated throughout these and other portions of the engine 100. For example, fuel and oil may be circulated throughout the gas turbine engine 100 and carry a portion of the heat generated during engine operation. Various fluids and media may be circulated throughout an engine during operation and may carry engine heat including, without limitation, air, fuel, oil, lubricating fluid, hydraulic fluid, thermally neutral heat-transfer fluid, or any other fluid suitable for circulating in a gas turbine engine 100.

[0022] In various embodiments of the present disclosure, the gas turbine engine 100 comprises a thermal management system utilizing one or more heat exchangers designed in accordance with the processes disclosed herein. Various heat exchangers may be incorporated into the thermal management system including, without limitation, air to air heat exchangers, air to fluid heat exchangers, and fluid to fluid heat exchangers. The present disclosure is not limited in this regard.

[0023] Referring now to FIG. 2, a heat exchanger 200 designed in accordance with a design process as described further herein, is illustrated, in accordance with various embodiments. In various embodiments, the heat exchanger 200 is a plate heat exchanger. Although illustrated and designed as a plate heat exchanger herein, the design process is not limited in this regard. For example, a similar design process could be utilized for other types of heat exchangers, such as double pipe heat exchangers (e.g., parallel flow, counter flow, or the like), compact heat exchangers (e.g., unmixed flow, mixed flow, etc.), shell and tube heat exchangers, or the like. The present disclosure is not limited in this regard.

[0024] In various embodiments, the heat exchanger 200 is an air-to-air heat exchanger. In this regard, the heat exchanger 200 is configured to receive a first airflow 201 that travels from a first side 202 laterally (e.g., substantially parallel to Y-axis of an XYZ coordinate system as shown in FIG. 2) to a second side 204, and a second airflow 205 that travels laterally from a third side 206 laterally (e.g., substantially parallel to the X-axis) to a fourth side 208 of the heat exchanger 200. In this regard, the air-to-air heat exchanger may comprise a cross-flow heat exchanger, in accordance with various embodiments. Although described further herein as comprising an air-to-air heat exchanger design process and article of manufacture, the present disclosure is not limited in this regard, and the design process can be utilized to design other types of heat exchangers, such as air to fluid heat exchangers or fluid to fluid heat exchangers, in accordance with various embodiments.

[0025] In various embodiments, the first airflow 201 comprises a first temperature and the second airflow 205 comprises a second temperature. In various embodiments, the first airflow 201 is a higher temperature than the second airflow 205. In this regard, in accordance with various embodiments, the heat exchanger 200 can be designed and configured to reduce a temperature of the first airflow 201 and/or to increase a temperature of the second airflow. In various embodiments, an inlet temperature of the first airflow 201 can be significantly greater than an inlet temperature of the second airflow. In this regard, the heat exchanger 200 can be susceptible to a significant temperature gradient, resulting in thermal growth differences between colder areas of the heat exchanger relative to hotter areas of the heat exchanger. In this regard, thermal stresses can have a significant impact on a life of a heat exchanger (e.g., due to low cycle fatigue from thermal stresses), in accordance with various embodiments.

[0026] In various embodiments, the heat exchanger 200 comprises a plurality of plates 210 (e.g., plates 212, 214, 216, 218, 219). Each plate in the plurality of plates can be spaced apart vertically (e.g., along the Z-axis) from an adjacent plate in the plurality of plates. For example, plate 212 can be spaced apart vertically from plate 214, plate 214 can be spaced apart vertically from plate 216, etc. In various embodiments, the heat exchanger 200 further comprises a plurality of sidewalls 220. In various embodiments, the two plates in the plurality of plates 210 and two sidewalls in the plurality of sidewalls 220 can define a fluid conduit therethrough. For example, plate 212, plate 214, sidewall 222, and sidewall 224 can define a fluid conduit 232 extending therethrough from the first side 202 laterally to the second side 204. In various embodiments, as described further herein, each fluid conduit in the heat exchanger 200 can comprise heat-transfer augmentors (e.g., fins, protrusions, turbulators, corrugations, etc.). The present disclosure is not limited in this regard.

[0027] Referring now to FIG. 3, a method 300 of designing and manufacturing a heat exchanger (e.g., heat exchanger 200 from FIG. 2) is illustrated in accordance with various embodiments. The method 300 comprises determining an outer profile for a heat exchanger design (step 302). In various embodiments, the initial outer profile determined in step 302 can be a design constraint (e.g., due to an envelope in which the heat exchanger is designed to fit) or the outer profile can be a variable input. In this regard, the outer profile can be changed during the design process and still be within the scope of this disclosure. The present disclosure is not limited in this regard.

[0028] In various embodiments, the method 300 further comprises dividing the heat exchanger design into a plurality of modules (step 304). With reference now to FIG. 4A, with like numerals depicting like elements, a design of the heat exchanger 200 from FIG. 2 can be divided in a grid like manner (e.g., from a top side to a bottom side as shown). For example, the heat exchanger 200 can be divided into a six-by-six grid of heat exchanger modules that form the heat exchanger 200. The plurality of modules 10 can be arranged in rows and columns. For example, modules 11, 21, 31, 41, 51, 61 can form a first row of modules, modules 21, 22, 32, 42, 52, 62 can form a second row of modules, modules 31, 32, 33, 43, 53, 63 can form a third row of modules, modules 41, 42, 43, 44, 45, 46 can form a fourth row of modules, modules 51, 52, 53, 54, 55, 56 can form a fifth row of modules, and/or modules 61, 62, 63, 64, 65, 66 can form a sixth row of modules). Similarly, for example, modules 11, 12, 13, 14, 15, 16 can form a first column of modules, modules 21, 22, 23, 24 25, 26 can form a second column of modules, modules 31, 32, 33, 34, 35, 36 can from a third column of modules, modules 41, 42, 43, 44, 45, 46 can form a fourth column of modules, modules 51, 52, 53, 54, 55, 56 can form a fifth column of modules, and/or modules 61, 62, 63, 64, 65, 66 can form a sixth column of modules.

[0029] In various embodiments, each module in the plurality of modules 10 can be configured, and modeled, as an independent heat exchanger. For example, with reference now to FIG. 3A and 3B, each module in the plurality of modules 10 can define a plurality of flow paths. For example, with reference to module 16, a first fluid conduit 161 of module 16 defines a first flow path that extends from an inlet 1611 to an outlet 1612, a second fluid conduit 162 of module 16 defines a second flow path that extends from an inlet 1621 to an outlet 1622, a third fluid conduit 163 of module 16 defines a third flow path that extends from an inlet 1631 to an outlet 1632, and a fourth fluid conduit 164 of module 16 defines a fourth flow path that extends from an inlet 1641 to an outlet 1642. The first fluid conduit 161 and the third fluid conduit 163 can be in a first direction (e.g., defining a Y-axis direction). Similarly, the second fluid conduit 162, and the fourth fluid conduit 164 can be in a second direction (e.g., defining an X-axis direction). In this regard, the first fluid conduit 161 and the third fluid conduit 163 can be configured to receive a first fluid that is a first temperature, and the second fluid conduit 162 and the fourth fluid conduit 164 can be configured to receive a second fluid that is a second temperature. The first temperature can be significantly greater than the second temperature as described previously herein.

[0030] Referring back to FIG. 3, the method 300 can further comprise determining an internal geometry of each conduit of each module in the plurality of modules based on a stress threshold for the module (step 306). In various embodiments, by using stress as an input in the design process, each module in the plurality of modules from step 304 can be designed and configured to maximize a heat-transfer coefficient while simultaneously ensuring that a deterministic-criteria for stress is met for the module.

[0031] With reference now to FIGs. 4B and 4C, and based on step 306, each fluid conduit (e.g., fluid conduit 161) of each module (e.g., module 16) in the plurality of modules 10 can comprise a unique internal geometry (e.g., heat-transfer augment arrangement 1161) relative to an adjacent fluid conduit (e.g., heat-transfer augmenter arrangement 1151 of fluid conduit 151) in an adjacent module (e.g., module 15) and/or relative to an adjacent fluid conduit (e.g., fluid conduit 162) in the same module (e.g., module 16). In this regard, since fluid conduit 161 defines an inlet of the first fluid (where the first fluid is hottest at the inlet of the heat exchanger 200) and the fluid conduit 162 defines an outlet for the second fluid (where the second fluid is hottest at the outlet of the heat exchanger 200), a thermal gradient of the plate (e.g., plate 214) disposed between the fluid conduits 161, 162 would be less compared to a thermal gradient of the plate (e.g., plate 214) in the adjacent module (e.g., module 56), which would experience a temperature of the second fluid in the fluid conduit 151 that is less than a temperature of the second fluid in the fluid conduit 161. In this regard, due to module 16 experiencing a lower temperature gradient relative to module 15, the module 16 can be configured for a greater amount of heat-transfer (i.e., have a heat-transfer augmenter arrangement 1161 that has a greater heat-transfer coefficient relative to the heat-transfer augmenter arrangement 1151). A "heat-transfer augmenter" as disclosed herein refers to any structure that disturbs fluid flow.

[0032] In various embodiments, a heat-transfer augmenter arrangement (e.g., heat-transfer augmenter arrangement 1161, 1151, etc.) can comprise a heat-transfer augmenter (or a plurality of heat-transfer augmenters). In various embodiments, the heat-transfer augmenter arrangement 1161 comprises a fin 410 that defines a wave 412 laterally (e.g., in the X-direction) from a first side 401 to a second side 402). Although illustrated as a sinusoidal wave, the present disclosure is not limited in this regard. For example, the wave 412 can comprise a square wave (FIG. 5A), a triangle wave (FIG. 5B), a sawtooth wave (FIG. 5C), or the like. The present disclosure is not limited in this regard. Although the wave 412 is illustrated as having an amplitude that is the same as a distance from plate 214 to plate 212, the present disclosure is not limited in this regard. For example, the wave 412 can extend only from plate 214, only from plate 212, or waves can be extending from both plates and still be within the scope of this disclosure. In various embodiments, the wave 412 extends through the conduit from the inlet to the outlet. For example, the wave 412 can extend from the inlet 1611 of the fluid conduit 161 to the outlet 1612 of the fluid conduit 161. In various embodiments, the wave 412 can comprise a uniform cross-sectional shape from the inlet 1611 to the outlet 1612. In this regard, the module 16 can be easier to manufacture. However, the present disclosure is not limited in this regard. For example, the wave 412 can have a variable cross-sectional shape (e.g., having a variable amplitude, a variable wavelength, a variable height, etc.). In various embodiments, the variable cross-sectional shape can vary in a smooth (or continuous manner) (i.e., a wavelength can vary continuously along a length of the wave 412). In various embodiments, the variable cross-sectional shape can vary in a discrete manner (i.e., a first section can have a first wavelength over a first length and can transition to a second section that has a second wavelength where the second wavelength is different from the first wavelength). The present disclosure is not limited in this regard.

[0033] In various embodiments, a heat-transfer augmenter arrangement (e.g., heat-transfer augmenter arrangement 1161, 1151, etc.) can comprise a plurality of fins. For example, with reference now to FIG. 6, exemplary heat-transfer augmenter arrangements for a heat-transfer surface 602 in a fluid conduit of a module as described previously herein are illustrated, in accordance with various embodiments. In various embodiments, the heat-transfer surface (e.g., a surface of plate 214 in fluid conduit 161) is an internal surface of a fluid conduit. In various embodiments, the heat-transfer augmenter arrangement (e.g., 1161, 1151, etc.) can comprise a straight fin arrangement 660, an elongated and angled arrangement 662, a snake fin arrangement 664, a chevron shaped arrangement 666, a pedestal fin arrangement 668, or the like. The present disclosure is not limited in this regard.

[0034] In various embodiments, as described previously herein, each conduit of each module in the plurality of modules 10 can comprise a heat-transfer augmenter arrangement that is different from an adjacent conduit in the respective module, or an adjacent conduit in an adjacent module. For example, with reference back to FIG. 4B, a wavelength of a wave in a first conduit (e.g., wave 412 in fluid conduit 161 can be different than a wavelength of a wave 422 in a second conduit 151 that is laterally adjacent to the first conduit 161. For example, the wavelength can be greater than or less than the adjacent wavelength. In this regard, the heat-transfer augmenter arrangement 1151 can be different than the heat-transfer augmenter arrangement 1161, which in turn can produce a different heat-transfer coefficient between the adjacent modules. In various embodiments, any variable for a heat-transfer augmenter arrangement 1161 can be varied and be within the scope of this disclosure. For example, for heat-transfer augmenters that have wave shapes, parameters that can be varied between fluid conduits include amplitude, wavelength, wave shape, etc. in accordance with various embodiments. For heat-transfer augmenters that have non-wave shapes (e.g., heat-transfer augmenter arrangements 660, 662, 664, 666, 668), parameters that can be varied between fluid conduits include fin density, fin height, fin length, fin thickness etc. The present disclosure is not limited in this regard. In various embodiments, a type of fin (e.g., straight fins vs. pedestal fins) can be varied between conduits. The present disclosure is not limited in this regard.

[0035] Referring back to FIG. 3, the method 300 further comprises manufacturing a heat exchanger based on the heat exchanger design (step 308). In this regard, a heat exchanger 200 can be manufactured that comprises a plurality of modules 10 as shown in FIGs. 4A-4C, wherein each module in the plurality of modules 10 is designed and configured as an independent heat exchanger. In this regard, as described previously herein, each module in the plurality of modules 10 can be designed and configured to produce a maximum heat-transfer coefficient (i.e., generate a maximum amount of heat-transfer) based on a stress threshold of the module in the plurality of modules 10. Since each module in the plurality of modules will be exposed to different temperatures during operation, thermal stresses in each module will be different. Thus, by maximizing a heat-transfer capability of each module based on a threshold stress, an overall heat-transfer capability for the heat exchanger 200 can be maximized by the design method 300.

[0036] Referring now to FIG. 7, a process 700 for designing a heat exchanger is illustrated, in accordance with various embodiments. In various embodiments, the process 700 comprises receiving, via a processor, boundary conditions for designing a modular heat exchanger (e.g., heat exchanger 200 from FIGs. 2 and 4A-C) (step 702). In various embodiments, the boundary conditions include an outer profile of a heat exchanger, a grid size for the modular heat exchanger, a material properties for the modular heat exchanger, a first fluid type, a second fluid type, a first fluid temperature at an inlet (e.g., inlet of fluid conduits (e.g., inlets on the first side 202 of the modular heat exchanger 200 from FIG. 2), a second fluid temperature at an inlet of fluid conduits (e.g., inlets on the third side 206 of the modular heat exchanger 200 from FIG. 2) , a first fluid velocity, and/or a second fluid velocity. In various embodiments, the boundary conditions can be outer limits of an operation envelope. For example, the first fluid temperature and the second fluid temperature can have a greatest difference in temperature that is expected during operation of the heat exchanger 200, the first fluid temperature can be a hottest temperature that is expected during operation, or the like. The present disclosure is not limited in this regard.

[0037] In various embodiments, the processor can determine a threshold stress envelope for the heat exchanger based on the material properties (i.e., the processor can retrieve data from a material property database and determine a threshold stress envelope (e.g., as a function of temperature or the like). In various embodiments, the threshold stress envelope can be provided as an input to the processor, instead of the material properties. The present disclosure is not limited in this regard. In various embodiments, the threshold stress envelope can be based on a yield stress of a material of the heat exchanger, an ultimate tensile stress of the material of the heat exchanger, or the like. The present disclosure is not limited in this regard. In various embodiments, the threshold stress envelope can be based on a margin of safety. In this regard, the threshold stress envelope can factor in potential deficiencies in the material, potential estimation deficiencies from a simulator, or the like.

[0038] In various embodiments, the process 700 further comprises determining, via the processor, a desired heat-transfer coefficient for each heat-transfer surface (e.g., a surface of plate 214 within fluid conduit 161 from FIGS. 4B-C) of each module (e.g., module 16) of the modular heat exchanger (e.g., heat exchanger 200 from FIGs. 2 and 4A-C) based on the boundary conditions (step 704). In this regard, by providing a stress threshold as an input into the simulator, and solving for a desired heat-transfer coefficient for each heat-transfer surface within each module in the plurality of modules 10 from FIGs. 4A-C, a number of design iterations can be minimized as a resulting design will meet structural deterministic criteria for the heat exchanger 200 that is designed via process 700, in accordance with various embodiments.

[0039] In various embodiments, in response to determining the desired heat-transfer coefficient, designing a heat-transfer arrangement of each heat-transfer surface for each fluid conduit of each module in the plurality of modules. In this regard, each conduit of each module can include a different heat-transfer augmenter arrangement, in accordance with various embodiments.

[0040] Benefits, other advantages, and solutions to problems have been described herein regarding specific embodiments. Furthermore, the connecting lines shown in the various figures contained herein are intended to represent exemplary functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections may be present in a practical system. However, the benefits, advantages, solutions to problems, and any elements that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential features or elements of the disclosure. The scope of the disclosure is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather "one or more." Moreover, where a phrase similar to "at least one of A, B, or C" is used in the claims, it is intended that the phrase be interpreted to mean that A alone may be present in an embodiment, B alone may be present in an embodiment, C alone may be present in an embodiment, or that any combination of the elements A, B and C may be present in a single embodiment; for example, A and B, A and C, B and C, or A and B and C. Different cross-hatching is used throughout the figures to denote different parts but not necessarily to denote the same or different materials.

[0041] Systems, methods, and apparatus are provided herein. In the detailed description herein, references to "one embodiment," "an embodiment," "various embodiments," etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether explicitly described. After reading the description, it will be apparent to one skilled in the relevant art(s) how to implement the disclosure in alternative embodiments.

[0042] Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. 112(f) unless the element is expressly recited using the phrase "means for." As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

[0043] Finally, any of the above-described concepts can be used alone or in combination with any or all the other above-described concepts. Although various embodiments have been disclosed and described, one of ordinary skill in this art would recognize that certain modifications would come within the scope of this disclosure. Accordingly, the description is not intended to be exhaustive or to limit the principles described or illustrated herein to any precise form. Many modifications and variations are possible considering the above teaching.

Claims

1. A method, comprising:

dividing a heat exchanger design into a plurality of modules, the plurality of modules arranged in a grid, each module in the plurality of modules including:

a first fluid conduit defining an inlet, an outlet, and a heat-transfer surface, and a first flow direction, and

a second fluid conduit defining a second inlet, a second outlet, a second heat-transfer surface, and a second flow direction, the second flow direction different from the first flow direction; and

determining a heat-transfer augmenter arrangement for the first fluid conduit and the second fluid conduit of each module in the plurality of modules based on a stress threshold of the module in the plurality of modules.

2. The method of claim 1, further comprising manufacturing a heat exchanger based on the heat exchanger design.

3. The method of claim 1 or 2, wherein:

the first fluid conduit of each module in the plurality of modules forms a first heat exchanger fluid conduit extending from a first side of the heat exchanger design to a second side of the heat exchanger design, and

the second fluid conduit of each module in the plurality of modules form together a second heat exchanger fluid conduit extending from a third side of the heat exchanger design to a fourth side of the heat exchanger design.

4. The method of claim 1, 2 or 3, wherein in response to determining the heat-transfer augmenter arrangement, the first fluid conduit in a first module of the plurality of modules has a first heat-transfer coefficient and the first fluid conduit in a second module of the plurality of modules has a second heat-transfer coefficient, the second heat-transfer coefficient being different than the first heat-transfer coefficient, and/or

wherein in response to determining the heat-transfer augmenter arrangement, the first fluid conduit in the first module of the plurality of modules includes a first wave and the first fluid conduit in the second module of the plurality of modules has a second wave, the second wave having a different wavelength than the first wave.

5. The method of any preceding claim, wherein the first fluid conduit is disposed vertically adjacent to the second fluid conduit.

6. The method of any preceding claim, wherein the determining the heat-transfer augmenter arrangement further comprises simulating each module in the plurality of modules as an independent heat exchanger in the heat exchanger design, and/or
wherein the heat exchanger design is a plate heat exchanger design.

7. A design process, comprising:

receiving, via a processor, boundary conditions for designing a modular heat exchanger, the modular heat exchanger comprising an M x N grid of modules, each module including at least two of a first fluid conduit defining a first flow direction interleaved and at least two off a second fluid conduit defining a second flow direction, the at least two of the first fluid conduit interleaved between the at least two of the second fluid conduit, the boundary conditions including a stress threshold envelope;
determining, via the processor and through a simulator, a desired heat-transfer coefficient for each heat-transfer surface in each fluid conduit of the modular heat exchanger based on the boundary conditions; and
in response to determining the desired heat-transfer coefficient, designing a heat-transfer augmenter arrangement for each fluid conduit in each module of the modular heat exchanger.

8. The design process of claim 7, wherein the boundary conditions further include an inlet temperature of a first fluid at a first side of the modular heat exchanger and a second inlet temperature of a second fluid at a second side of the modular heat exchanger, and/or wherein M x N is at least 3 x 3.

9. The design process of claim 7 or 8, wherein:

the first fluid conduit of each module in the plurality of modules forms a first heat exchanger fluid conduit extending from a first side of the modular heat exchanger to a second side of the modular heat exchanger, and
the second fluid conduit of each module in the plurality of modules form together a second heat exchanger fluid conduit extending from a third side of the modular heat exchanger to a fourth side of the modular heat exchanger.

10. The design process of claim 7, 8 or 9, wherein the designing the heat-transfer augmenter arrangement includes designing a first wave in the first fluid conduit of a first module and designing a second wave in the first fluid conduit of a second module, the first wave having a different wavelength than the second wave, wherein, optionally, the designing the heat-transfer augmenter arrangement includes designing a first heat-transfer augmenter in the first fluid conduit of the first module and designing a second heat-transfer augmenter in the first fluid conduit of the second module, wherein the first heat-transfer augmenter is different from the second heat-transfer augmenter.

11. A modular heat exchanger, comprising:
a grid of heat exchanger modules, the grid of heat exchanger modules comprising:

a first side disposed laterally opposite a second side,
a first plurality of fluid conduits, each fluid conduit in the first plurality of fluid conduits extending from the first side to the second side, each fluid conduit in the first plurality of fluid conduits extending through a first set of modules in the grid of heat exchanger modules,
a first fluid conduit of a first module in the grid of heat exchanger modules, a second fluid conduit of a second module in the grid of heat exchanger modules, and a third fluid conduit of a third module in the grid of heat exchanger modules defining a respective fluid conduit in the first plurality of fluid conduits, and
a first heat-transfer augmenter arrangement of a first heat-transfer surface in the first fluid conduit being different from a second heat-transfer augmenter arrangement of a second heat-transfer surface of the second fluid conduit.

12. The modular heat exchanger of claim 11, wherein a third heat-transfer augmenter arrangement of a third heat-transfer surface of the third fluid conduit is different from the first heat-transfer augmenter arrangement and the second heat-transfer augmenter arrangement.

13. The modular heat exchanger of claim 11 or 12, wherein the grid of heat exchanger modules further comprises a third side disposed laterally opposite a fourth side, a second plurality of fluid conduits extending from the third side to the fourth side, each fluid conduit in the second plurality of fluid conduits extending through a second set of modules in the grid of heat exchanger modules.

14. The modular heat exchanger of claim 13, wherein a fourth fluid conduit of a fourth module in the grid of heat exchanger modules, a fifth fluid conduit of a fifth module in the grid of heat exchanger modules, and the first module in the grid of heat exchanger modules defines a sixth fluid conduit in the second plurality of fluid conduits.

15. The modular heat exchanger of claim 14, wherein a fourth heat-transfer augmenter arrangement of a fourth heat-transfer surface in the fourth fluid conduit is different from a fifth heat-transfer augmenter arrangement of a fifth heat-transfer surface of the fifth fluid conduit, and/or
wherein a sixth augmenter heat-transfer arrangement of a sixth heat-transfer surface of the sixth fluid conduit is different from the fourth heat-transfer augmenter arrangement and the fifth heat-transfer augmenter arrangement.

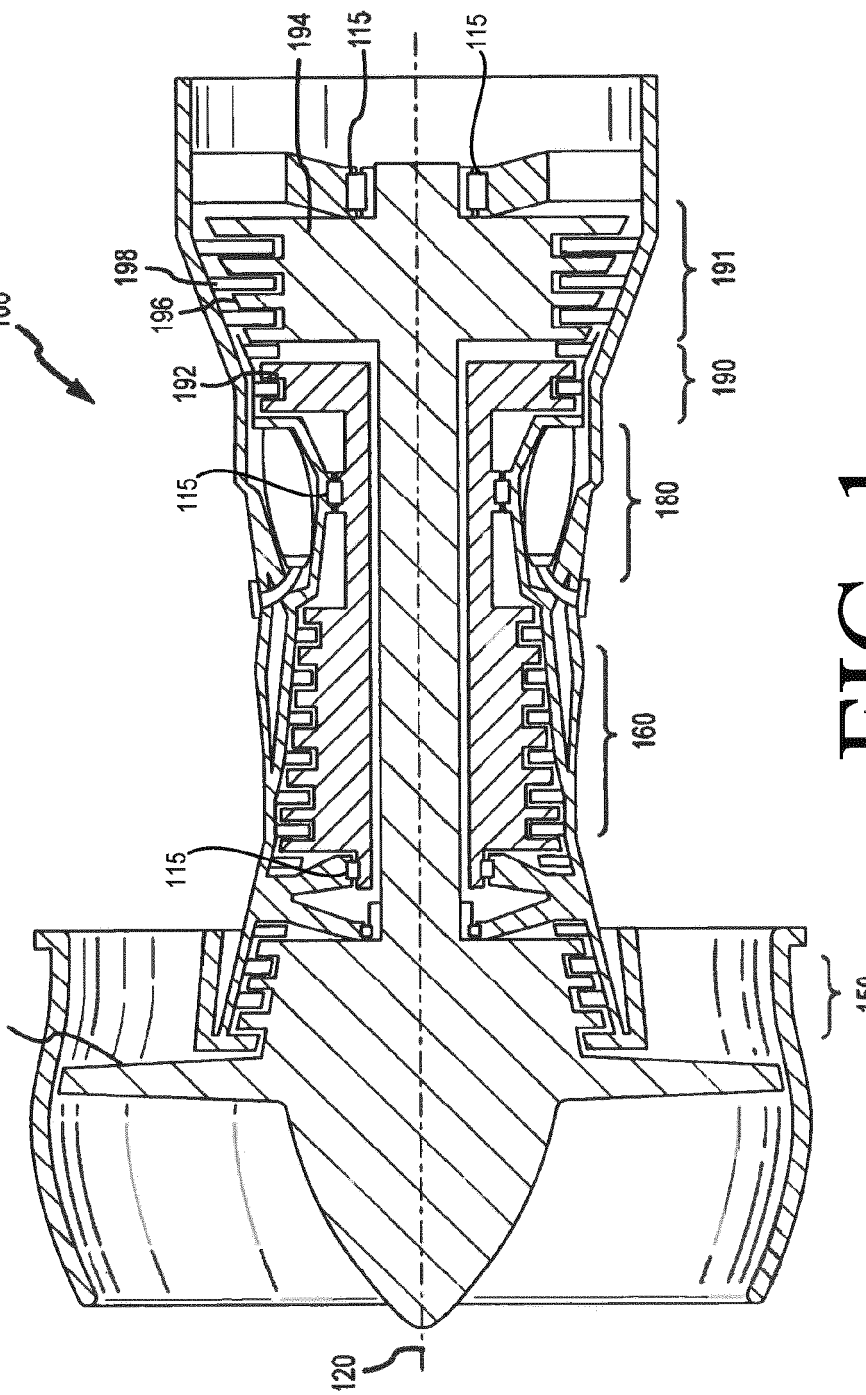

FIG. 1

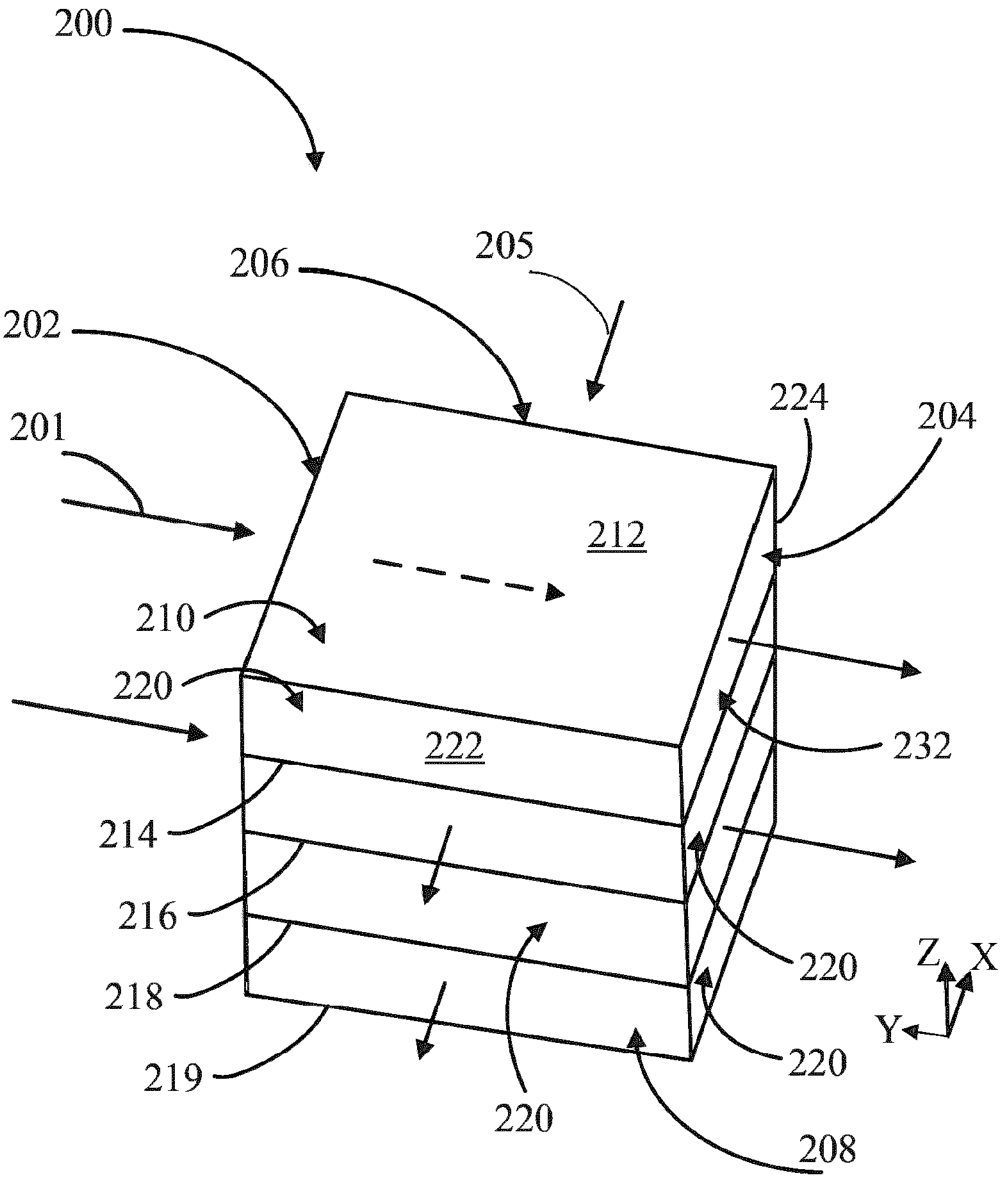
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FIG. 2

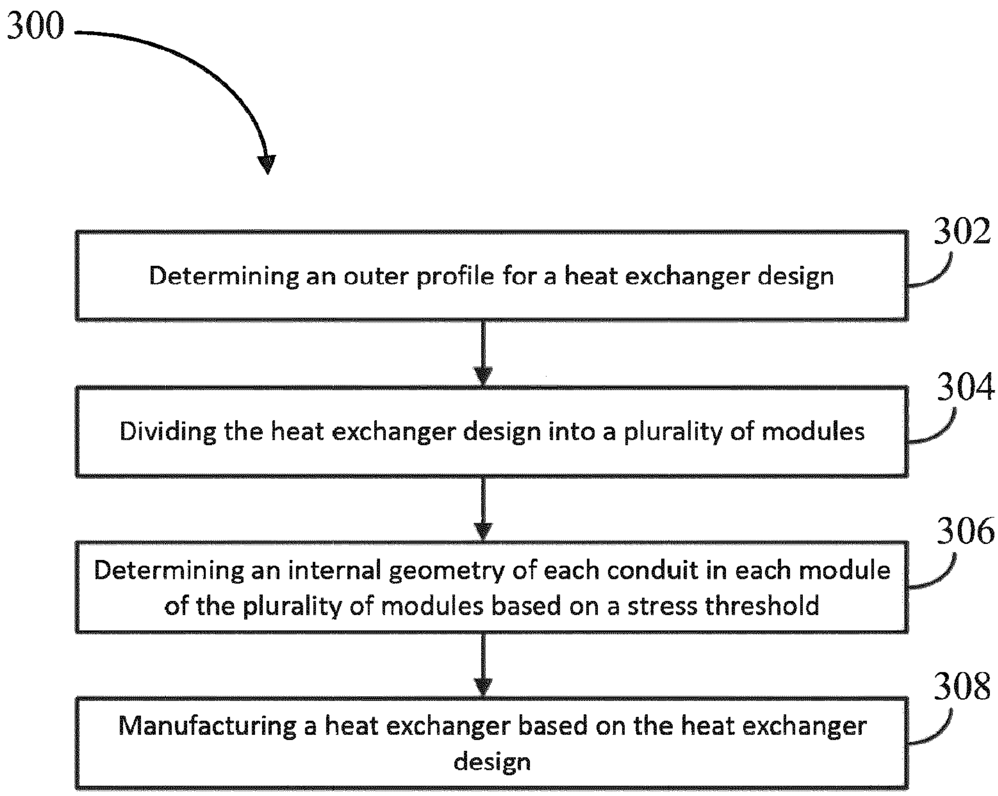
300
302
Determining an outer profile for a heat exchanger design
304
Dividing the heat exchanger design into a plurality of modules
306
Determining an internal geometry of each conduit in each module of the plurality of modules based on a stress threshold
308
Manufacturing a heat exchanger based on the heat exchanger design

FIG. 3

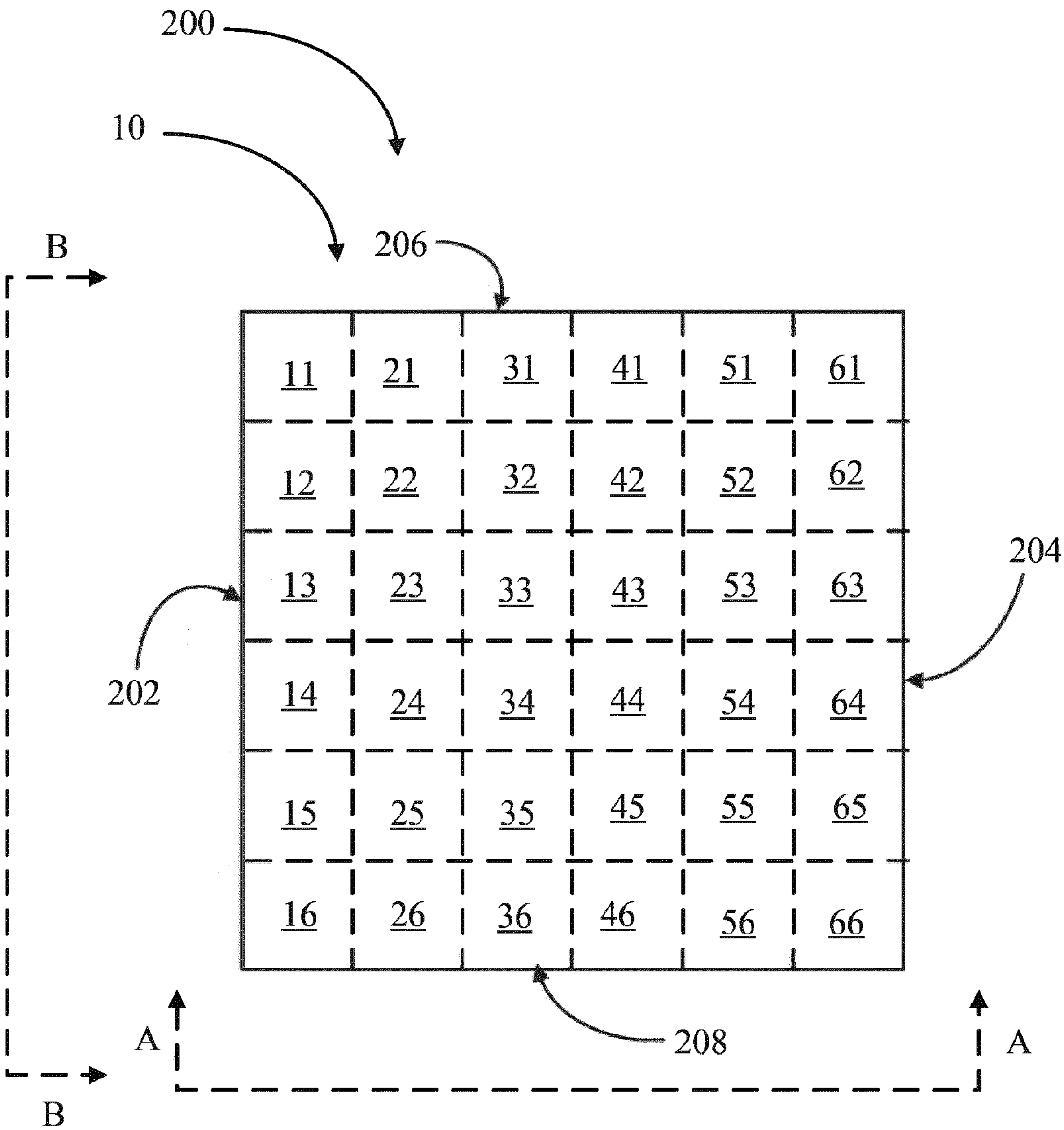
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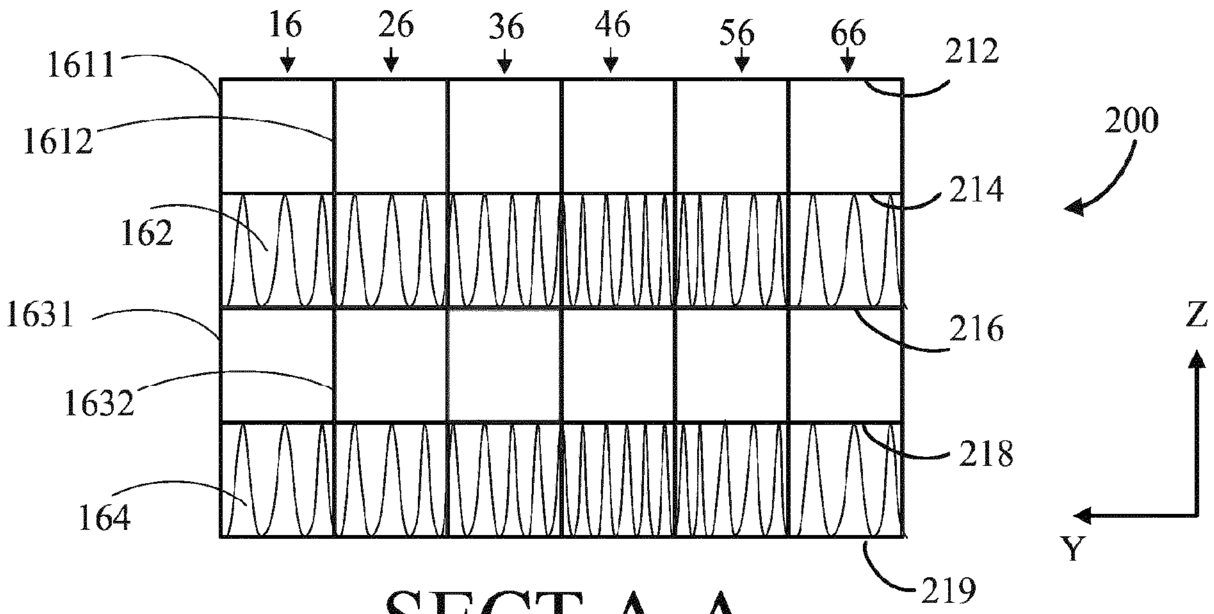
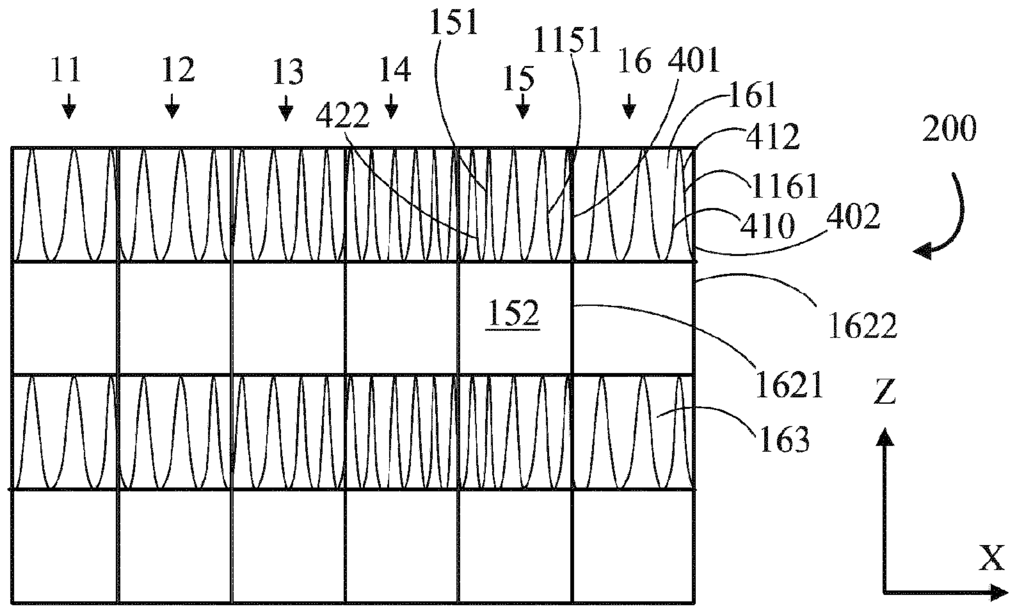
FIG. 4A



SECT A-A

FIG. 4B



SECT B-B

FIG. 4C

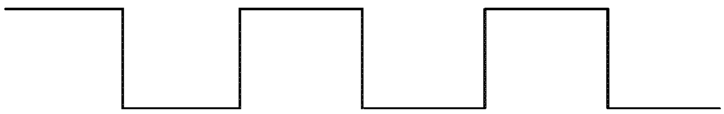


FIG. 5A

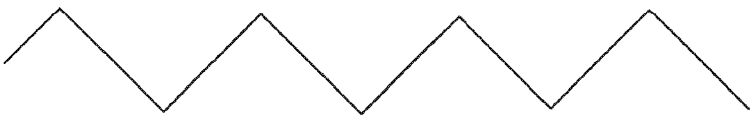


FIG. 5B

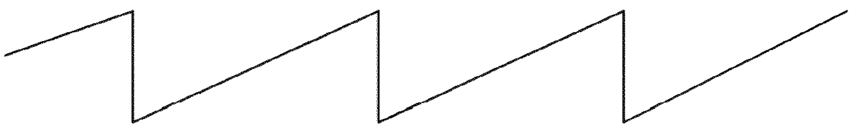


FIG. 5C

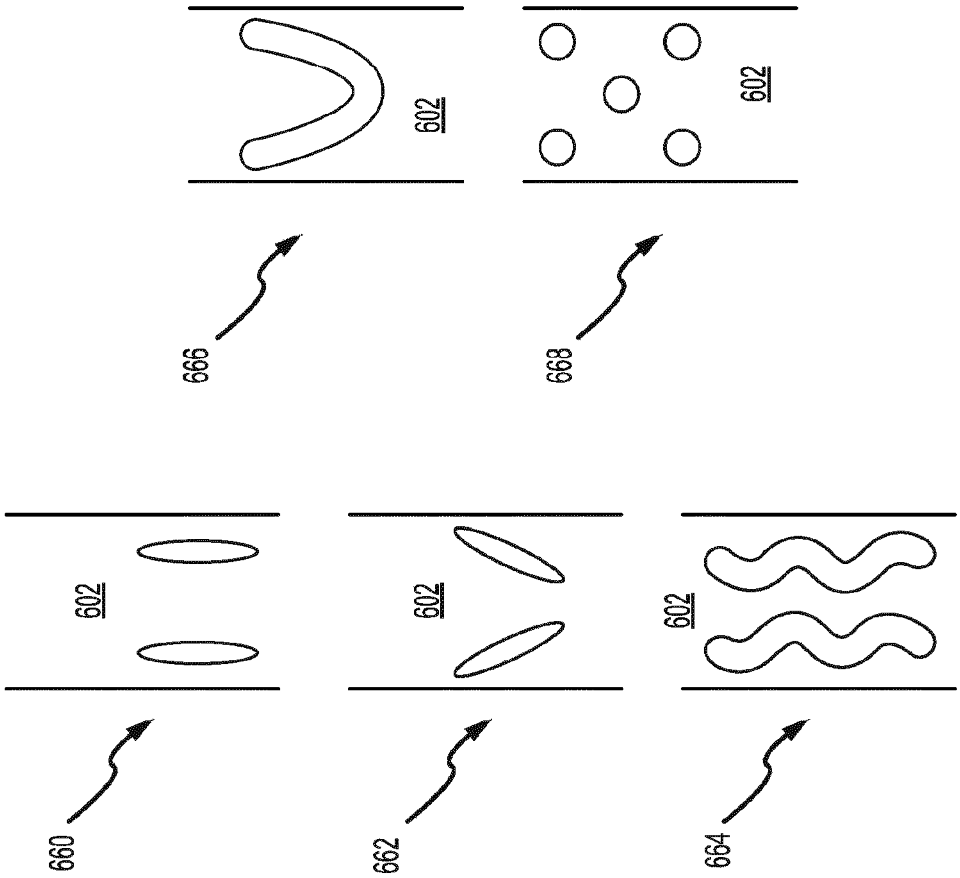


FIG. 6

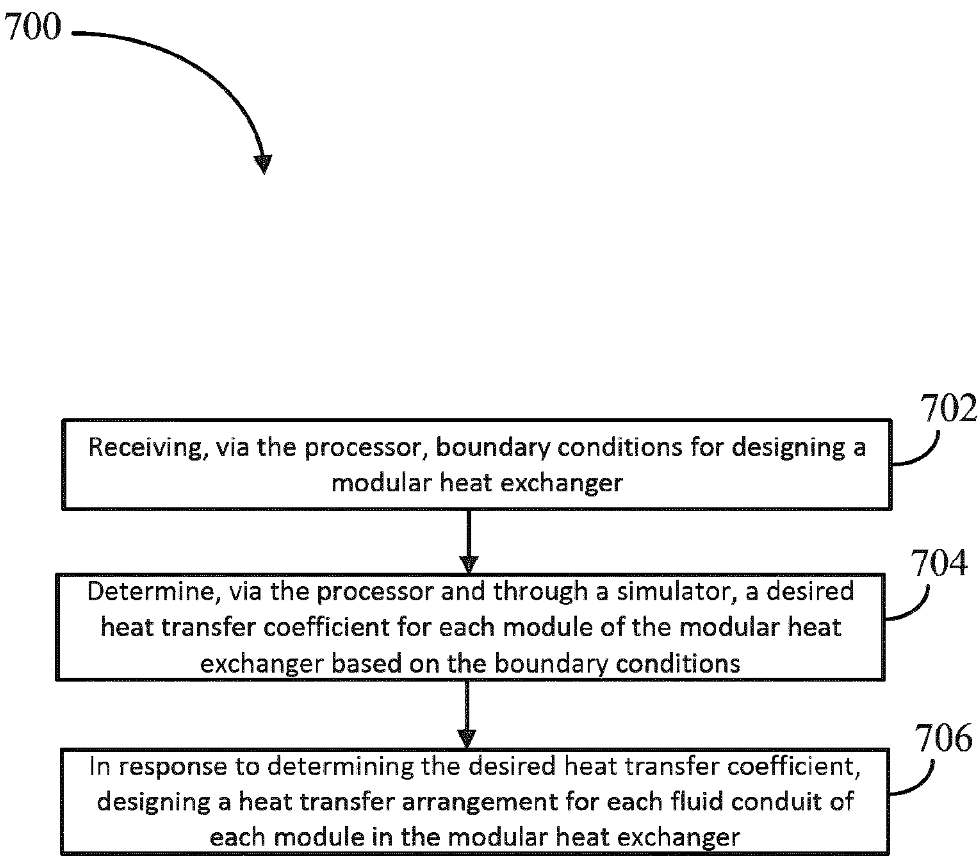

700
Receiving, via the processor, boundary conditions for designing a modular heat exchanger
702
Determine, via the processor and through a simulator, a desired heat transfer coefficient for each module of the modular heat exchanger based on the boundary conditions
704
In response to determining the desired heat transfer coefficient, designing a heat transfer arrangement for each fluid conduit of each module in the modular heat exchanger
706

FIG. 7

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EUROPEAN SEARCH REPORT

Application Number
EP 23 20 1793

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X	US 10 222 142 B2 (HONEYWELL INT INC [US]) 5 March 2019 (2019-03-05) * figure 9 * -----	1,11	
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F28F
F28D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	9 February 2024	Martínez Rico, Celia

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