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(54) **MAGNETO CALORIC DEVICE WITH CONTINUOUS PUMP**

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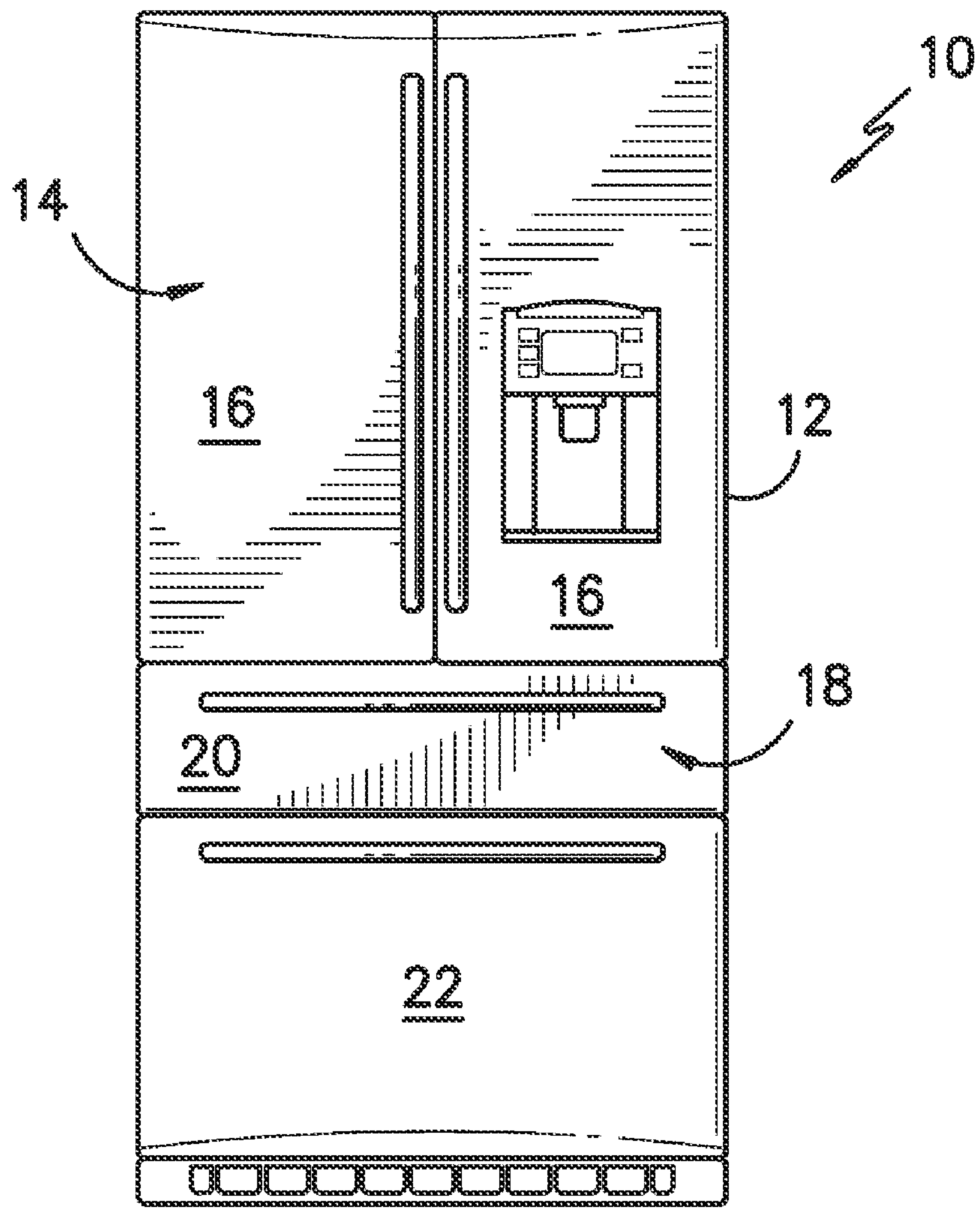
(57) **ABSTRACT**

A heat pump system having magneto caloric material positioned in a continuously rotating regenerator is provided. The magneto caloric material is staged so that as the regenerator is rotated, a portion of the material is cycled in and out of a magnetic field in a continuous manner. A heat transfer fluid is circulated through the magneto caloric material simultaneously along at least two paths to provide for the transfer of heat both to and from the material in a cyclic manner. The magneto caloric material may include zones having different temperature ranges of responsiveness to the magnetic field. An appliance using a heat pump system based on magneto caloric material is also provided.



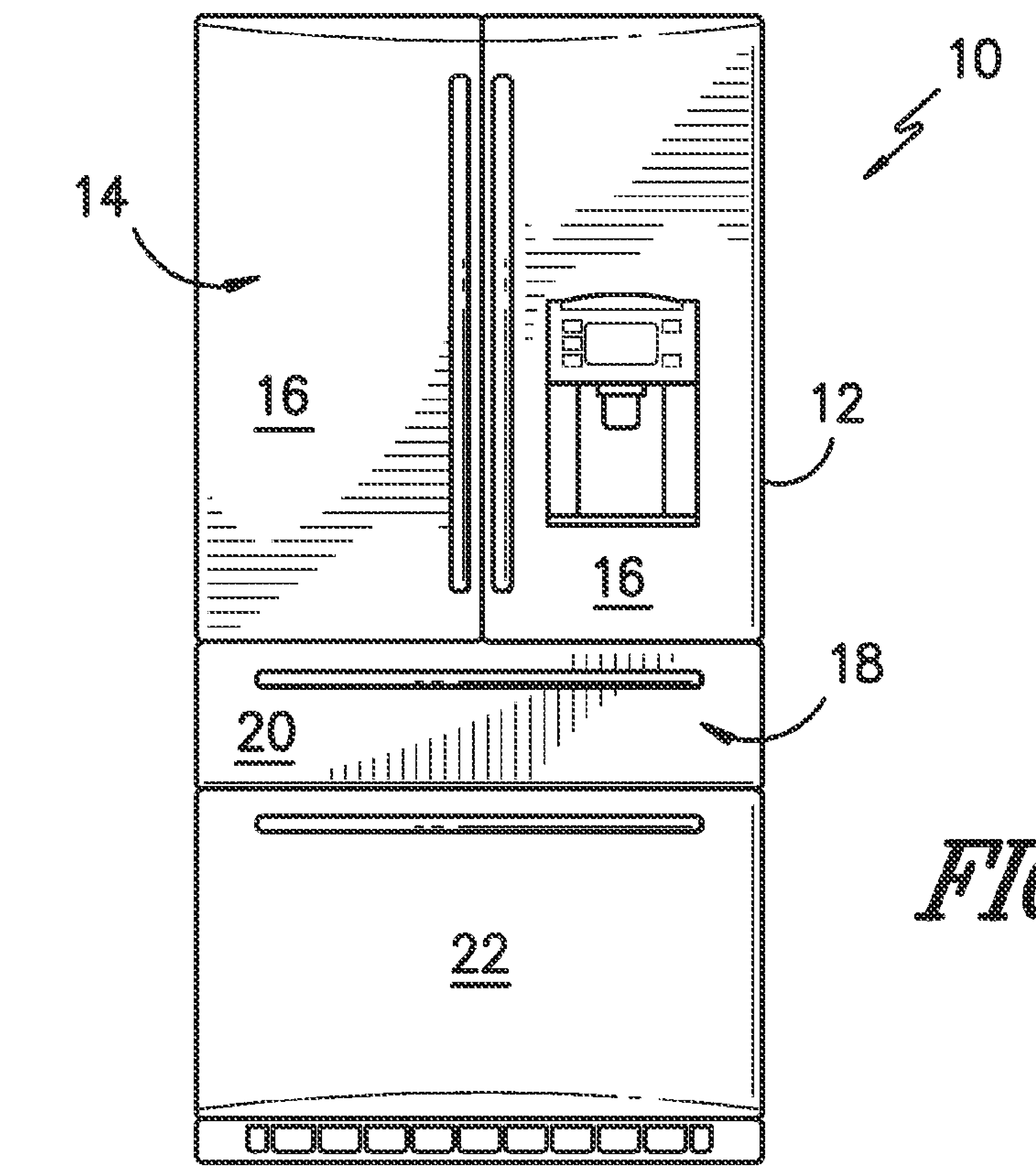


FIG. —1—

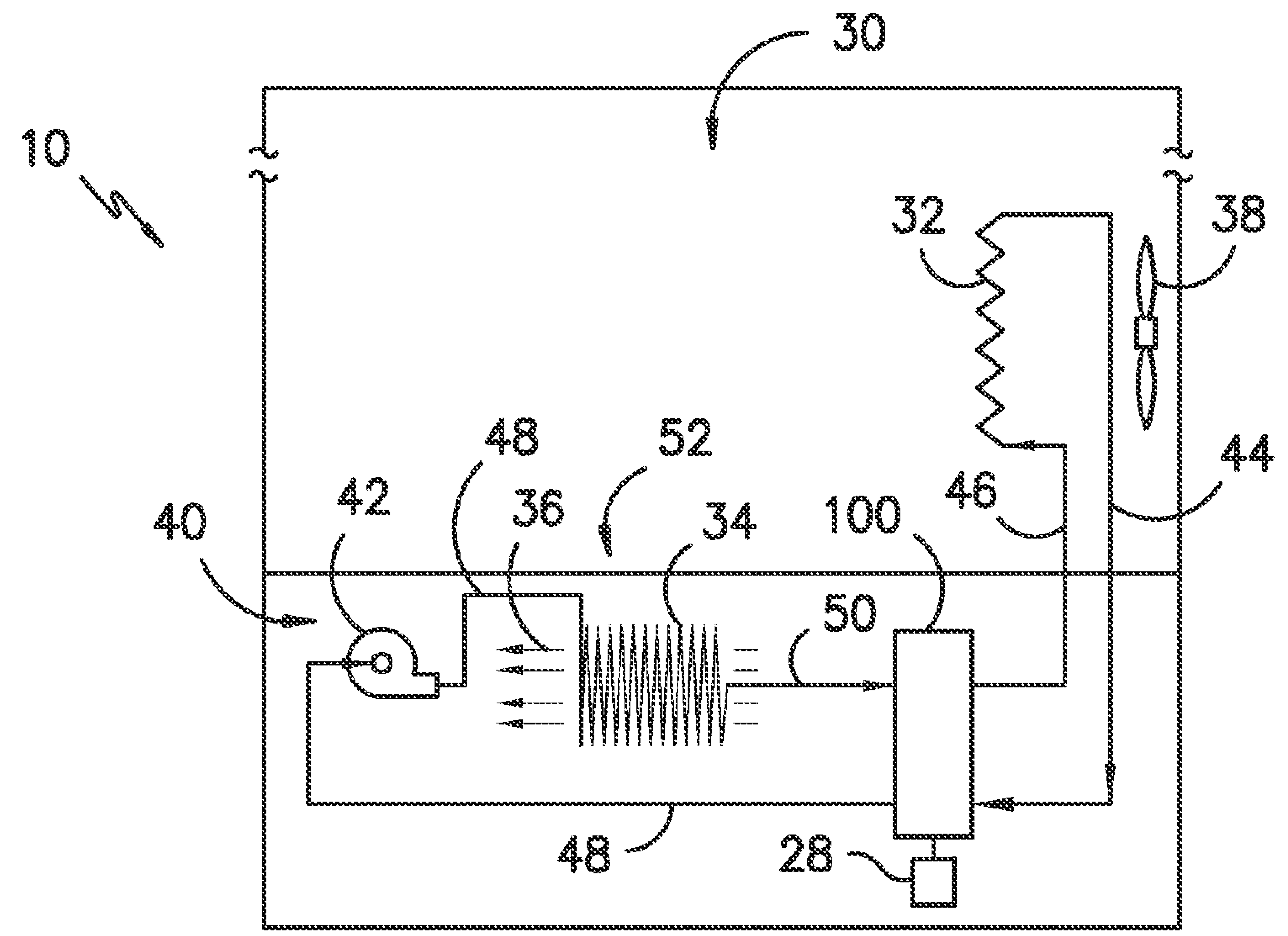


FIG. —2—

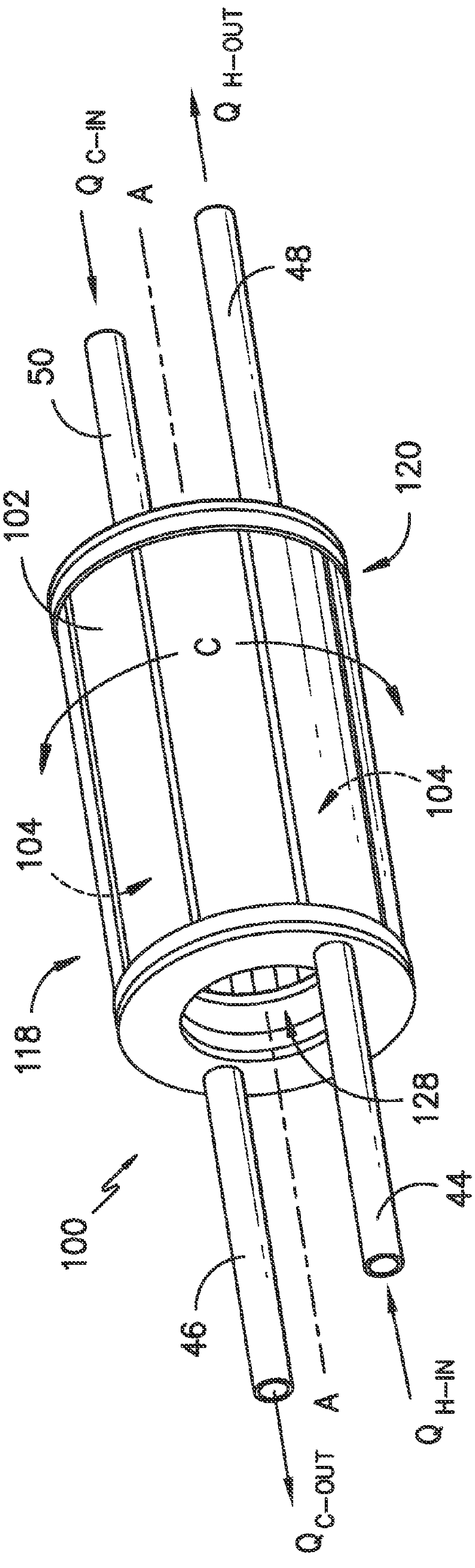

Q H-OUT
Q C-IN
A
48
50
120
102
C
104
104
118
128
100
44
46
A
Q H-IN
Q C-OUT

FIG. —3—

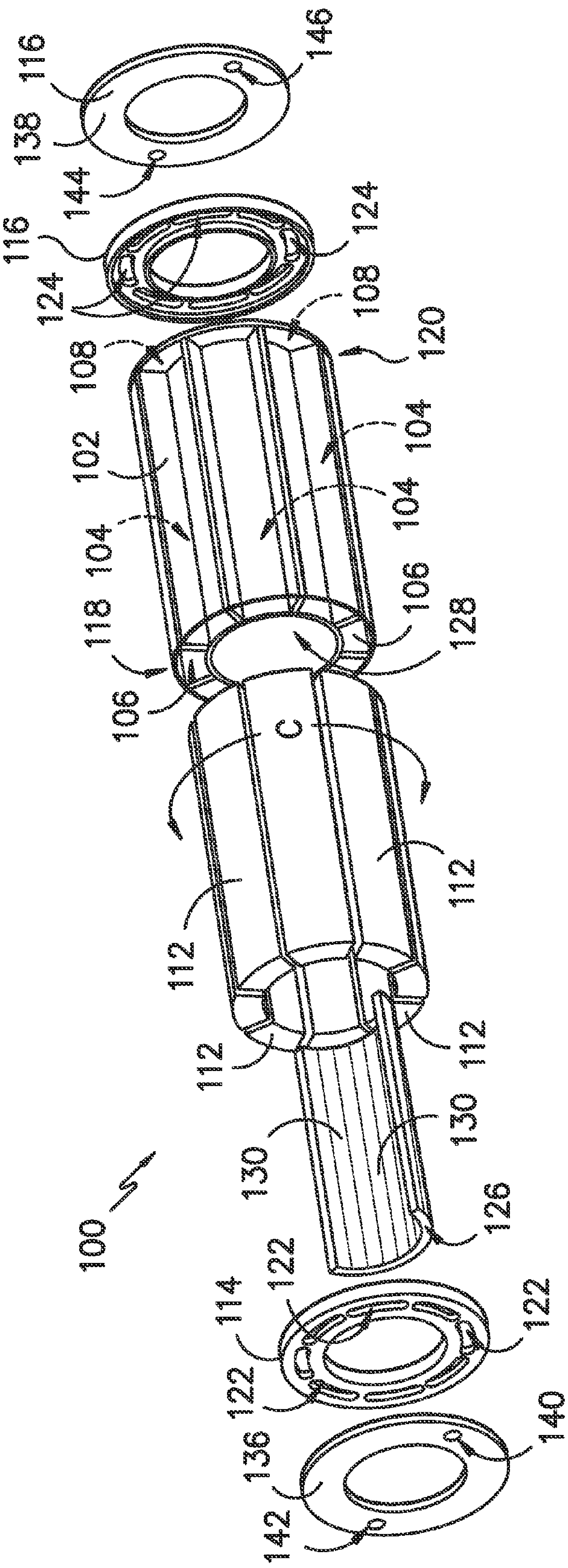

116
146
138
144
116
124
124
108
108
108
120
102
104
104
104
104
118
106
106
128
C
112
112
112
112
112
130
130
130
126
100
122
122
114
122
122
136
140
142

FIG. —4—

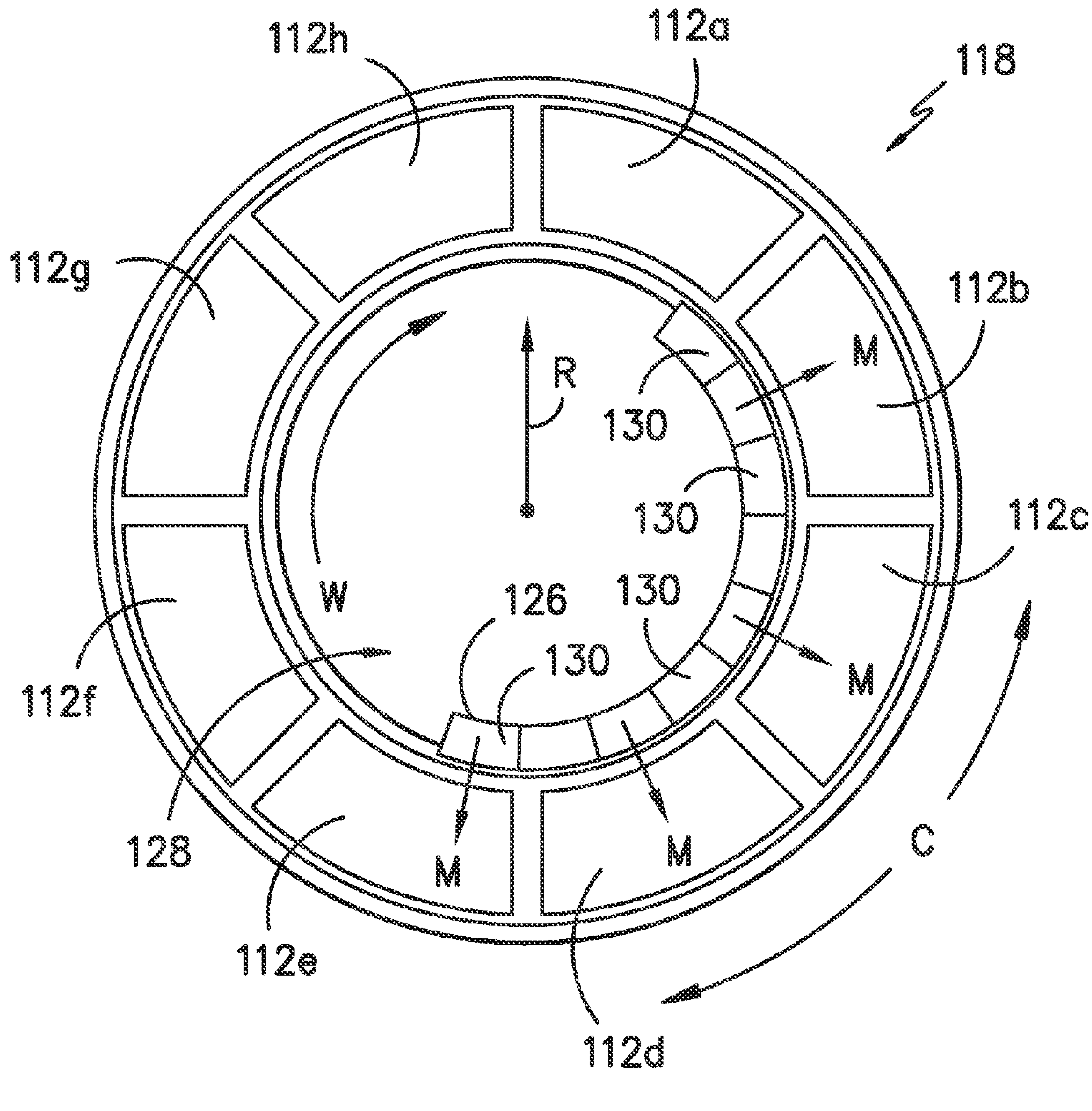

112h
112a
118
112g
112b
R
M
130
130
112c
W
126
130
130
M
112f
128
M
M
C
112e
112d

FIG. —5—

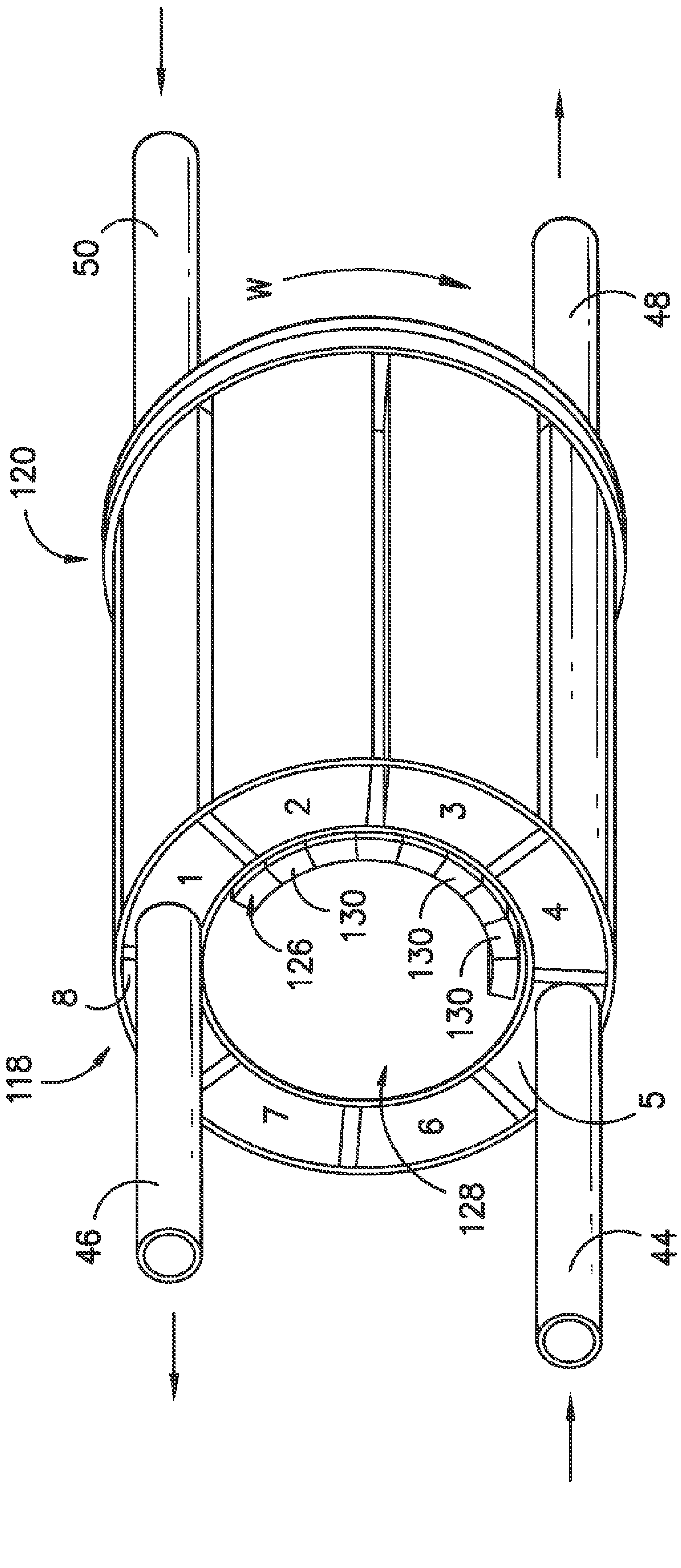


FIG. —6—

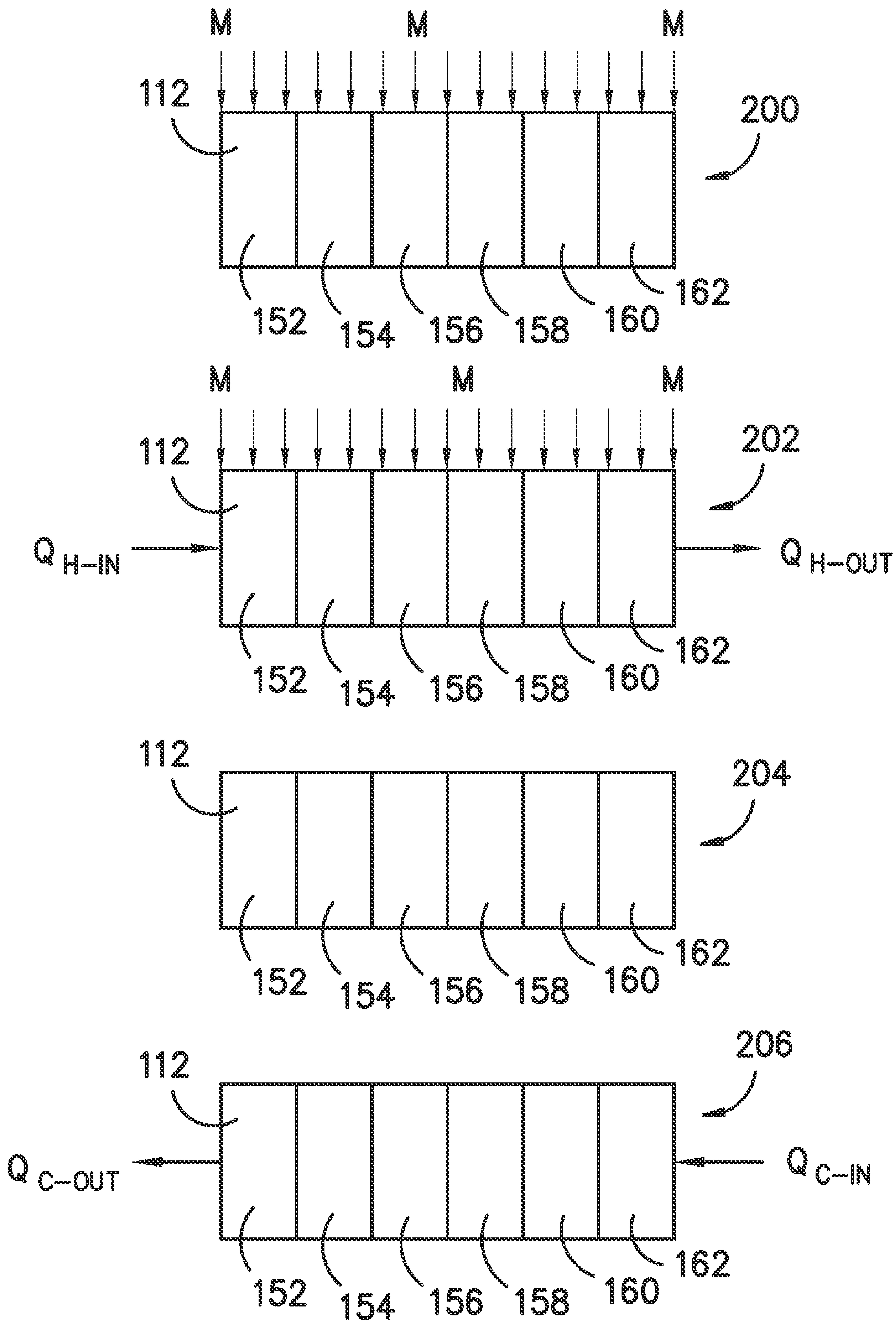

M
M
M
112
200
152
154
156
158
160
162
M
M
M
112
202
Q H-IN
Q H-OUT
152
154
156
158
160
162
112
204
152
154
156
158
160
162
112
206
Q C-OUT
Q C-IN
152
154
156
158
160
162

FIG. —7—

MAGNETO CALORIC DEVICE WITH CONTINUOUS PUMP

FIELD OF THE INVENTION

[0001] The subject matter of the present disclosure relates generally to a heat pump system that uses magneto caloric materials to exchange heat with a circulating heat transfer fluid.

BACKGROUND OF THE INVENTION

[0002] Conventional refrigeration technology typically utilizes a heat pump that relies on compression and expansion of a fluid refrigerant to receive and reject heat in a cyclic manner so as to effect a desired temperature change or i.e. transfer heat energy from one location to another. This cycle can be used to provide e.g., for the receiving of heat from a refrigeration compartment and the rejecting of such heat to the environment or a location that is external to the compartment. Other applications include air conditioning of residential or commercial structures. A variety of different fluid refrigerants have been developed that can be used with the heat pump in such systems.

[0003] While improvements have been made to such heat pump systems that rely on the compression of fluid refrigerant, at best such can still only operate at about 45 percent or less of the maximum theoretical Carnot cycle efficiency. Also, some fluid refrigerants have been discontinued due to environmental concerns. The range of ambient temperatures over which certain refrigerant-based systems can operate may be impractical for certain locations. Other challenges with heat pumps that use a fluid refrigerant exist as well.

[0004] Magneto caloric materials (MCMs)—i.e. materials that exhibit the magneto caloric effect—provide a potential alternative to fluid refrigerants for heat pump applications. In general, the magnetic moments of an MCM will become more ordered under an increasing, externally applied magnetic field and cause the MCM to generate heat. Conversely, decreasing the externally applied magnetic field will allow the magnetic moments of the MCM to become more disordered and allow the MCM to absorb heat. Some MCMs exhibit the opposite behavior—i.e. generating heat when the magnetic field is removed (which are sometimes referred to as para-magneto caloric material but both types are referred to collectively herein as magneto caloric material or MCM). The theoretical Carnot cycle efficiency of a refrigeration cycle based on an MCM can be significantly higher than for a comparable refrigeration cycle based on a fluid refrigerant. As such, a heat pump system that can effectively use an MCM would be useful.

[0005] Challenges exist to the practical and cost competitive use of an MCM, however. In addition to the development of suitable MCMs, equipment that can attractively utilize an MCM is still needed. Provision should be made for the transfer or heat to and from the MCM, preferably in a continuous manner so that the equipment does not operate in a start and stop fashion that can be inefficient. Currently proposed equipment may require relatively large and expensive magnets, may be impractical for use in e.g., appliance refrigeration, and may not otherwise operate with enough efficiency to justify capital cost.

[0006] Additionally, as stated above, the ambient conditions under which a heat pump may be needed can vary substantially. For example, for a refrigerator appliance placed in a garage or located in a non-air conditioned space, ambient temperatures can range from below freezing to over 90° F. Some MCMs are capable of accepting and generating heat only within a much narrower temperature range than presented by such ambient conditions.

[0007] Accordingly, a heat pump system that can address certain challenges such as those identified above would be useful. Such a heat pump system that can also be used in e.g., a refrigerator appliance would also be useful.

BRIEF DESCRIPTION OF THE INVENTION

[0008] The present invention provides a heat pump system having magneto caloric material positioned in a continuously rotating regenerator. The magneto caloric material is staged so that as the regenerator is rotated, a portion of the material is cycled in and out of a magnetic field in a continuous manner. A heat transfer fluid is circulated through the magneto caloric material simultaneously along at least two paths to provide for the transfer of heat both to and from the material in a cyclic manner. The magneto caloric material may include zones having different temperature ranges of responsiveness to the magnetic field. An appliance using a heat pump system based on magneto caloric material is also provided. The heat pump may also be used in other applications for heating, cooling, or both. Additional aspects and advantages of the invention will be set forth in part in the following description, or may be apparent from the description, or may be learned through practice of the invention.

[0009] In one exemplary embodiment, the present invention provides a heat pump system that includes a regenerator housing defining a circumferential direction and rotatable about an axial direction, the axial direction extending between a first end and a second end of the regenerator housing. The regenerator housing includes a plurality of chambers with each chamber extending longitudinally along the axial direction between a pair of openings. The plurality of chambers are arranged proximate to each other along the circumferential direction. A plurality of stages are provide with each stage comprising magneto caloric material positioned within one of the plurality of chambers and extending along the axial direction.

[0010] This exemplary embodiment further includes a pair of valves with a first valve attached to the first end of the regenerator housing and a second valve attached to the second end of the regenerator housing. The first valve and second valve each include a plurality of apertures spaced apart from each other along the circumferential direction with each aperture positioned adjacent to one of the pair of openings of one of the plurality of chambers. A magnetic element is positioned proximate to the regenerator housing and extends along the axial direction. The magnetic element creates a magnetic field and is positioned so that a subset of the plurality of stages are moved in and out of the magnetic field as the regenerator housing is rotated about the axial direction.

[0011] This exemplary system also includes a pair of seals with a first seal positioned adjacent to the first valve and a second seal adjacent to the second valve such that the regenerator housing and the pair of valves are rotatable relative to the pair of seals. The first seal and the second seal each include a pair of ports positioned in an opposing manner relative to each other and also positioned so that each port can selectively align with at least one of the pair of openings of the plurality of chambers as the regenerator housing is rotated about the axial direction.

[0012] In still another exemplary embodiment, the present invention provides a refrigerator appliance that includes a compartment for the storage of food items; a first heat exchanger for the removal of heat from the compartment; a second heat exchanger for the delivery of heat removed by the first heat exchanger to a location external of the compartment; a pump for circulating a heat transfer fluid between the first heat exchanger and the second heat exchanger; and a heat pump in fluid communication with the pump. The heat pump is also in fluid communication with the first heat exchanger through a first inlet port and a first outlet port and is in fluid communication with the second heat exchanger by a second inlet port and a second outlet port.

[0013] For this exemplary embodiment, the heat pump further includes a regenerator housing defining a circumferential direction and rotatable about an axial direction, the axial direction extending between a first end and a second end of the regenerator housing. The regenerator housing includes a plurality of chambers with each chamber extending longitudinally along the axial direction between a pair of openings. The plurality of chambers are arranged proximate to each other along the circumferential direction.

[0014] A plurality of stages are provided with each stage including magneto caloric material positioned within one of the plurality of chambers and extending along the axial direction. A pair of valves includes a first valve attached to the first end of the regenerator housing and a second valve attached to the second end of the regenerator housing. The first valve and second valve each include a plurality of apertures spaced apart from each other along the circumferential direction with each aperture positioned adjacent to one of the pair of openings of one of the plurality of chambers. A magnetic element is positioned proximate to the regenerator housing and extends along the axial direction. The magnetic element creates a magnetic field. The magnetic element is positioned so that a subset of the plurality of stages are moved within the magnetic field as the regenerator housing is rotated about the axial direction.

[0015] A pair of seals are provided with a first seal positioned adjacent to the first valve and a second seal positioned adjacent to the second valve such that the regenerator housing and the pair of valves are rotatable relative to the pair of seals. The first seal includes the first inlet port and the first outlet port. The second seal includes the second inlet port and a second outlet port. The first inlet port and the first outlet port are positioned in an opposing manner about the first seal and second inlet port and the second outlet port are positioned in an opposing manner about the second seal. The first inlet port and the second outlet port are positioned for fluid communication with the pair of openings of at least one chamber at a time as the regenerator housing is rotated about the axial direction so that heat transfer fluid from the first heat exchanger may receive heat from the stage of magneto caloric material located in the at least one chamber. The second inlet port and the first outlet port are positioned for fluid communication with the pair of openings of at least one other chamber at a time as the regenerator housing is rotated about the axial direction so that heat transfer fluid from the second heat exchanger may deliver heat to the magneto caloric material in the at least one other chamber.

[0016] These and other features, aspects and advantages of the present invention will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] A full and enabling disclosure of the present invention, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures, in which:

[0018] FIG. **1** provides an exemplary embodiment of a refrigerator appliance of the present invention.

[0019] FIG. **2** is a schematic illustration of an exemplary heat pump system of the present invention positioned in an exemplary refrigerator with a machinery compartment and a refrigerated compartment.

[0020] FIG. **3** provides a perspective view of an exemplary heat pump of the present invention.

[0021] FIG. **4** is an exploded view of the exemplary heat pump of FIG. **3**.

[0022] FIG. **5** is a cross-sectional view of the exemplary heat pump of FIG. **3**.

[0023] FIG. **6** is perspective view of the exemplary heat pump of FIG. **3**. Seals located at the ends of a regenerator housing have been removed for purposes of further explanation of this exemplary embodiment of the invention as set forth below.

[0024] FIG. **7** is a schematic representation of various steps in the use of a stage of the heat pump of FIG. **3**.

DETAILED DESCRIPTION OF THE INVENTION

[0025] Reference now will be made in detail to embodiments of the invention, one or more examples of which are illustrated in the drawings. Each example is provided by way of explanation of the invention, not limitation of the invention. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. For instance, features illustrated or described as part of one embodiment can be used with another embodiment to yield a still further embodiment. Thus, it is intended that the present invention covers such modifications and variations as come within the scope of the appended claims and their equivalents.

[0026] Referring now to FIG. **1**, an exemplary embodiment of an appliance refrigerator **10** is depicted as an upright refrigerator having a cabinet or casing **12** that defines a number of internal storage compartments or chilled chambers. In particular, refrigerator appliance **10** includes upper fresh-food compartments **14** having doors **16** and lower freezer compartment **18** having upper drawer **20** and lower drawer **22**. The drawers **20**, **22** are "pull-out" type drawers in that they can be manually moved into and out of the freezer compartment **18** on suitable slide mechanisms. Refrigerator **10** is provided by way of example only. Other configurations for a refrigerator appliance may be used as well including appliances with only freezer compartments, only chilled compartments, or other combinations thereof different from that shown in FIG. **1**. In addition, the heat pump and heat pump system of the present invention is not limited to appliances and may be used in other applications as well such as e.g., air-conditioning, electronics cooling devices, and others. Thus, it should be understood that while the use of a heat pump to provide cooling within a refrigerator is provided by way of example herein, the present invention may also be used to provide for heating applications as well.

[0027] FIG. **2** is a schematic view of another exemplary embodiment of a refrigerator appliance **10** including a refrigeration compartment **30** and a machinery compartment **40**. In particular, machinery compartment **30** includes a heat pump system **52** having a first heat exchanger **32** positioned in the refrigeration compartment **30** for the removal of heat therefrom. A heat transfer fluid such as e.g., an aqueous solution, flowing within first heat exchanger **32** receives heat from the refrigeration compartment **30** thereby cooling its contents. A fan **38** may be used to provide for a flow of air across first heat exchanger **32** to improve the rate of heat transfer from the refrigeration compartment **30**.

[0028] The heat transfer fluid flows out of first heat exchanger **32** by line **44** to heat pump **100**. As will be further described herein, the heat transfer fluid receives additional heat from magneto caloric material (MCM) in heat pump **100** and carries this heat by line **48** to pump **42** and then to second heat exchanger **34**. Heat is released to the environment, machinery compartment **40**, and/or other location external to refrigeration compartment **30** using second heat exchanger **34**. A fan **36** may be used to create a flow of air across second heat exchanger **34** and thereby improve the rate of heat transfer to the environment. Pump **42** connected into line **48** causes the heat transfer fluid to recirculate in heat pump system **52**. Motor **28** is in mechanical communication with heat pump **100** as will further described.

[0029] From second heat exchanger **34** the heat transfer fluid returns by line **50** to heat pump **100** where, as will be further described below, the heat transfer fluid loses heat to the MCM in heat pump **100**. The now colder heat transfer fluid flows by line **46** to first heat exchanger **32** to receive heat from refrigeration compartment **30** and repeat the cycle as just described.

[0030] Heat pump system **52** is provided by way of example only. Other configurations of heat pump system **52** may be used as well. For example, lines **44**, **46**, **48**, and **50** provide fluid communication between the various components of the heat pump system **52** but other heat transfer fluid recirculation loops with different lines and connections may also be employed. For example, pump **42** can also be positioned at other locations or on other lines in system **52**. Still other configurations of heat pump system **52** may be used as well.

[0031] FIGS. **3**, **4**, **5**, and **6** depict various views of an exemplary heat pump **100** of the present invention. Heat pump **100** includes a regenerator housing **102** that extends longitudinally along an axial direction between a first end **118** and a second end **120**. The axial direction is defined by axis A-A about which regenerator housing **102** rotates. A radial direction R is defined by a radius extending orthogonally from the axis of rotation A-A (FIG. **5**). A circumferential direction is indicated by arrows C.

[0032] Regenerator housing **102** defines a plurality of chambers **104** that extend longitudinally along the axial direction defined by axis A-A. Chambers **104** are positioned proximate or adjacent to each other along circumferential direction C. Each chamber **104** includes a pair of openings **106** and **108** positioned at opposing ends **118** and **120** of regenerator housing **102**.

[0033] Heat pump **100** also includes a plurality of stages **112** that include MCM. Each stage **112** is located in one of the chambers **104** and extends along the axial direction. For the exemplary embodiment shown in the figures, heat pump **100** includes eight stages **112** positioned adjacent to each other along the circumferential direction as shown and extending longitudinally along the axial direction. As will be understood by one of skill in the art using the teachings disclosed herein, a different number of stages **112** other than eight may be used as well.

[0034] A pair of valves **114** and **116** are attached to regenerator housing **102** and rotate therewith along circumferential direction C. More particularly, a first valve **114** is attached to first end **118** and a second valve **116** is attached to second end **120**. Each valve **114** and **116** includes a plurality of apertures **122** and **124**, respectively. For this exemplary embodiment, apertures **122** and **124** are configured as circumferentially-extending slots that are spaced apart along circumferential direction C. Each aperture **122** is positioned adjacent to a respective opening **106** of a chamber **104**. Each aperture **124** is positioned adjacent to a respective opening **108** of a chamber **104**. Accordingly, a heat transfer fluid may flow into a chamber **104** through a respective aperture **122** and opening **106** so as to flow through the MCM in a respective stage **112** and then exit through opening **108** and aperture **124**. A reverse path can be used for flow of the heat transfer fluid in the opposite direction through the stage **112** of a given chamber **104**.

[0035] Regenerator housing **102** defines a cavity **128** that is positioned radially inward of the plurality of chambers **104** and extends along the axial direction between first end **118** and second end **120**. A magnetic element **126** is positioned within cavity **128** and, for this exemplary embodiment, extends along the axial direction between first end **118** and second end **120**. Magnetic element **126** provides a magnetic field that is directed radially outward as indicated by arrows M in FIG. **5**.

[0036] The positioning and configuration of magnetic element **126** is such that only a subset of the plurality of stages **112** is within magnetic field M at any one time. For example, as shown in FIG. **5**, stages **112***a* and **112***e* are partially within the magnetic field while stages **112***b*, **112***c*, and **112***d* are fully within the magnetic field M created by magnetic element **126**. Conversely, the magnetic element **126** is configured and positioned so that stages **112***f*, **112***g*, and **112***h* are completely or substantially out of the magnetic field created by magnetic element **126**. However, as regenerator housing **102** is continuously rotated along the circumferential direction as shown by arrow W, the subset of stages **112** within the magnetic field will continuously change as some stages **112** will enter magnetic field M and others will exit.

[0037] A pair of seals **136** and **138** is provided with the seals positioned in an opposing manner at the first end **118** and second end **120** of regenerator housing **102**. First seal **136** has a first inlet port **140** and a first outlet port **142** and is positioned adjacent to first valve **114**. As shown, ports **140** and **142** are positioned 180 degrees apart about the circumferential direction C of first seal **114**. However, other configurations may be used. For example, ports **140** and **142** may be positioned within a range of about 170 degrees to about 190 degrees about the circumferential direction C as well. First valve **114** and regenerator housing **102** are rotatable relative to first seal **136**. Ports **140** and **142** are connected with lines **44** and **46** (FIG. **1**), respectively. As such, the rotation of regenerator housing **102** about axis A-A sequentially places lines **44** and

46 in fluid communication with at least two stages **112** of MCM at any one time as will be further described.

[0038] Second seal **138** has a second inlet port **144** and a second outlet port **146** and is positioned adjacent to second valve **116**. As shown, ports **144** and **146** are positioned 180 degrees apart about the circumferential direction C of second seal **116**. However, other configurations may be used. For example, ports **144** and **146** may be positioned within a range of about 170 degrees to about 190 degrees about the circumferential direction C as well. Second valve **116** and regenerator housing **102** are rotatable relative to second seal **138**. Ports **144** and **146** are connected with lines **50** and **48** (FIG. **1**), respectively. As such, the rotation of regenerator housing **102** about axis A-A sequentially places lines **48** and **50** in fluid communication with at least two stages **112** of MCM at any one time as will be further described. Notably, at any one time during rotation of regenerator housing **102**, lines **46** and **50** will each be in fluid communication with at least one stage **112** while lines **44** and **48** will also be in fluid communication with at least one other stage **112** located about 180 degrees away along the circumferential direction.

[0039] FIG. **7** illustrates an exemplary method of the present invention using a schematic representation of stage **112** of MCM in regenerator housing **102** as it rotates in the direction of arrow W between positions **1** through **8** as shown in FIG. **6**. During step **200**, stage **112** is fully within magnetic field M, which causes the magnetic moments of the material to orient and the MCM to heat as part of the magneto caloric effect. Ordering of the magnetic field is created and maintained as stage **112** is rotated sequentially through positions **2**, **3**, and then **4** (FIG. **6**) as regenerator housing **102** is rotated in the direction of arrow W. During the time at positions **2**, **3**, and **4**, the heat transfer fluid dwells in the MCM of stage **112** and, therefore, is heated. More specifically, the heat transfer fluid does not flow through stage **112** because the openings **106**, **108**, **122**, and **124** corresponding to stage **112** in positions **2**, **3**, and **4** are not aligned with any of the ports **140**, **142**, **144**, or **146**.

[0040] In step **202**, as regenerator housing **102** continues to rotate in the direction of arrow W, stage **112** will eventually reach position **5**. As shown in FIGS. **3** and **6**, at position **5** the heat transfer fluid can flow through the material as first inlet port **140** is now aligned with an opening **122** in first valve **114** and an opening **106** at the first end **118** of stage **112** while second outlet port **146** is aligned with an opening **124** in second valve **116** at the second end **120** of stage **112**. As indicated by arrow Q_{H-OUT}, heat transfer fluid in stage **112**, now heated by the MCM, can travel out of regenerator housing **102** and along line **48** to the second heat exchanger **34**. At the same time, and as indicated by arrow Q_{H-IN}, heat transfer fluid from first heat exchanger **32** flows into stage **112** from line **44** when stage **112** is at position **5**. Because heat transfer fluid from the first heat exchanger **32** is relatively cooler than the MCM in stage **112**, the MCM will lose heat to the heat transfer fluid.

[0041] Referring again to FIG. **7** and step **204**, as regenerator housing **102** continues to rotate in the direction of arrow W, stage **112** is moved sequentially through positions **6**, **7**, and **8** where stage **112** is completely or substantially out of magnetic field M. The absence or lessening of the magnetic field is such that the magnetic moments of the material become disordered and the MCM absorbs heat as part of the magneto caloric effect. During the time in positions **6**, **7**, and **8**, the heat transfer fluid dwells in the MCM of stage **112** and, therefore, is cooled by losing heat to the MCM as the magnetic moments disorder. More specifically, the heat transfer fluid does not flow through stage **112** because the openings **106**, **108**, **122**, and **124** corresponding to stage **112** when in positions **6**, **7**, and **8** are not aligned with any of the ports **140**, **142**, **144**, or **146**.

[0042] Referring to step **206** of FIG. **7**, as regenerator housing **102** continues to rotate in the direction of arrow W, stage **112** will eventually reach position **1**. As shown in FIGS. **3** and **6**, at position **1** the heat transfer fluid in stage **112** can flow through the material as second inlet port **144** is now aligned with an opening **124** in second valve **116** and an opening **108** at the second end **120** while first outlet port **142** is aligned with an opening **122** in first valve **114** and opening **106** at first end **118**. As indicated by arrow Q_{C-OUT}, heat transfer fluid in stage **112**, now cooled by the MCM, can travel out of regenerator housing **102** and along line **46** to the first heat exchanger **32**. At the same time, and as indicated by arrow Q_{C-IN}, heat transfer fluid from second heat exchanger **34** flows into stage **112** from line **50** when stage **112** is at position **5**. Because heat transfer fluid from the second heat exchanger **34** is relatively warmer than the MCM in stage **112** at position **5**, the MCM will lose some of its heat to the heat transfer fluid. The heat transfer fluid now travels along line **46** to the first heat exchanger **32** to receive heat and cool the refrigeration compartment **30**.

[0043] As regenerator housing **102** is rotated continuously, the above described process of placing stage **112** in and out of magnetic field M is repeated. Additionally, the size of magnetic field M and regenerator housing **102** are such that a subset of the plurality of stages **112** is within the magnetic field at any given time during rotation. Similarly, a subset of the plurality of stages **112** are outside (or substantially outside) of the magnetic field at any given time during rotation. Additionally, at any given time, there are at least two stages **112** through which the heat transfer fluid is flowing while the other stages remain in a dwell mode. More specifically, while one stage **112** is losing heat through the flow of heat transfer fluid at position **5**, another stage **112** is receiving heat from the flowing heat transfer fluid at position **1**, while all remaining stages **112** are in dwell mode. As such, the system can be operated continuously to provide a continuous recirculation of heat transfer fluid in heat pump system **52** as stages **112** are each sequentially rotated through positions **1** through **8**.

[0044] As will be understood by one of skill in the art using the teachings disclosed herein, the number of stages for housing **102**, the number of ports in valve **114** and **116**, and/or other parameters can be varied to provide different configurations of heat pump **100** while still providing for continuous operation. For example, each valve could be provided within two inlet ports and two outlet ports so that heat transfer fluid flows through at least four stages **112** at any particular point in time. Alternatively, regenerator housing **102**, valves **122** and **124**, and/or seals **136** and **138** could be constructed so that e.g., at least two stages are in fluid communication with an inlet port and outlet port at any one time. Other configurations may be used as well.

[0045] As stated, stage **112** includes MCM extending along the axial direction of flow. The MCM may be constructed from a single magneto caloric material or may include multiple different magneto caloric materials. By way of example, appliance **10** may be used in an application where the ambient temperature changes over a substantial range. However, a specific magneto caloric material may exhibit the magneto caloric effect over only a much narrower temperature range. As such, it may be desirable to use a variety of magneto caloric materials within a given stage to accommodate the wide range of ambient temperatures over which appliance **10** and/or heat pump **100** may be used.

[0046] Accordingly, as shown in FIG. **7**, each stage **112** can be provided with zones **152**, **154**, **156**, **158**, **160**, and **162** of different magneto caloric materials. Each such zone includes an MCM that exhibits the magneto caloric effect at a different temperature or a different temperature range than an adjacent zone along the axial direction of stage **112**. For example, zone **152** may exhibit the magnet caloric effect at a temperature less than the temperature at which zone **154** exhibits the magnet caloric effect, which may be less than such temperature for zone **156**, and so on. Other configurations may be used as well. By configuring the appropriate number sequence of zones of MCM, heat pump **100** can be operated over a substantial range of ambient temperatures.

[0047] Referring now to FIGS. **4**, **5**, and **6**, magnetic element **126** is constructed in the shape of an arc from a plurality of magnets **130** arranged in a Halbach array for this exemplary embodiment. More specifically, magnets **130** are arranged so that magnetic element **126** provides a magnetic field M located radially outward of magnetic element **126** and towards regenerator housing **102** while minimal or no magnetic field is located radially-inward towards the axis of rotation A-A. Magnetic field M may be aligned in a curve or arc shape. A variety of other configurations may be used as well for magnetic element **126** and/or its resulting magnetic field. For example, magnetic element **126** could be constructed from a first plurality of magnets positioned in cavity **128** in a Halbach array that directs the field outwardly while a second plurality of magnetics is positioned radially outward of regenerator housing **102** and arranged to provide a magnetic field that is located radially inward to the regenerator housing **102**. In still another embodiment, magnetic element **128** could be constructed from a plurality of magnets positioned radially outward of regenerator housing **102** and arranged to provide a magnetic field that is located radially inward towards the regenerator housing **102**. Other configurations of magnetic element **128** may be provided as well. For example, coils instead of magnets may be used to create the magnetic field desired.

[0048] For this exemplary embodiment, the arc created by magnetic element **128** provides a magnetic field extending circumferentially about 180 degrees. In still another embodiment, the arc created by magnetic element **128** provides a magnetic field extending circumferentially in a range of about 170 degrees to about 190 degrees.

[0049] A motor **28** is in mechanical communication with regenerator housing **102** and provides for rotation of housing **102** about axis A-A. By way of example, motor **28** may be connected directly with housing **102** by a shaft or indirectly through a gear box. Other configurations may be used as well.

[0050] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

What is claimed is:

1. A heat pump system, comprising:

a regenerator housing defining a circumferential direction and rotatable about an axial direction, the axial direction extending between a first end and a second end of the regenerator housing, the regenerator housing comprising a plurality of chambers with each chamber extending longitudinally along the axial direction between a pair of openings, the plurality of chambers arranged proximate to each other along the circumferential direction;

a plurality of stages, each stage comprising magneto caloric material positioned within one of the plurality of chambers and extending along the axial direction;

a pair of valves comprising a first valve attached to the first end of the regenerator housing and a second valve attached to the second end of the regenerator housing, the first valve and second valve each comprising a plurality of apertures spaced apart from each other along the circumferential direction with each aperture positioned adjacent to one of the pair of openings of one of the plurality of chambers;

a magnetic element positioned proximate to the regenerator housing and extending along the axial direction, the magnetic element creating a magnetic field, the magnetic element positioned so that a subset of the plurality of stages are moved in and out of the magnetic field as the regenerator housing is rotated about the axial direction; and

a pair of seals comprising a first seal positioned adjacent to the first valve and a second seal adjacent to the second valve such that the regenerator housing and the pair of valves are rotatable relative to the pair of seals, the first seal and the second seal each comprising a pair of ports positioned in an opposing manner relative to each other and also positioned so that each port can selectively align with at least one of the pair of openings of the plurality of chambers as the regenerator housing is rotated about the axial direction.

2. The heat pump system of claim **1**, wherein the regenerator housing defines a radial direction and further comprises a cavity positioned radially-inward of the plurality of chambers, wherein the magnetic element is positioned within the cavity of the regenerator housing.

3. The heat pump system of claim **2**, wherein the magnetic element comprises a plurality of magnets arranged in the shape of an arc and configured to project a magnetic field substantially along a radially-outward direction.

4. The heat pump system of claim **3**, wherein the arc formed by the plurality of magnets extends about the circumferential direction by an amount in the range of about 170 degrees to about 190 degrees.

5. The heat pump system of claim **4**, wherein the plurality of magnets are arranged in a HalBach array.

6. The heat pump system of claim of claim **1**, wherein the regenerator housing defines a radial direction and further comprises a cavity positioned radially-inward of the plurality of chambers, and wherein the magnetic element further comprising a first plurality of magnets positioned within the cavity and a second plurality of magnets positioned radially outward of the regenerator housing.

7. The heat pump system of claim of claim **1**, wherein the pair of ports on each of the pair of seals are positioned about the circumferential direction within a range of about 170 degrees to about 190 degrees from each other.

8. The heat pump system of claim of claim **1**, wherein each stage of the plurality of stages comprises a plurality of zones of magneto caloric material arranged sequentially along the axial direction, wherein each zone comprises magneto caloric material having a different temperature range over which a change in the magnetic moments of the magneto caloric material occurs as compared to an adjacent zone.

9. The heat pump system of claim of claim **8**, wherein the plurality of zones are arranged along the axial direction so that the temperature range over which the change in the magnetic moments of magneto caloric material occurs increases sequentially from zone to zone along the axial direction.

10. The heat pump system of claim **1**, further comprising a motor in mechanical communication with the regenerator housing and configured for rotating the regenerator housing about the axial direction.

11. A refrigerator appliance, comprising:

a compartment for the storage of food items;

a first heat exchanger for the removal of heat from the compartment;

a second heat exchanger for the delivery of heat removed by the first heat exchanger to a location external of the compartment;

a pump for circulating a heat transfer fluid between the first heat exchanger and the second heat exchanger;

a heat pump in fluid communication with the pump, the heat pump also in fluid communication with the first heat exchanger through a first inlet port and a first outlet port, the heat pump also in fluid communication with the second heat exchanger by a second inlet port and a second outlet port, the heat pump further comprising

a regenerator housing defining a circumferential direction and rotatable about an axial direction, the axial direction extending between a first end and a second end of the regenerator housing, the regenerator housing comprising a plurality of chambers with each chamber extending longitudinally along the axial direction between a pair of openings, the plurality of chambers arranged proximate to each other along the circumferential direction;

a plurality of stages, each stage comprising magneto caloric material positioned within one of the plurality of chambers and extending along the axial direction;

a pair of valves comprising a first valve attached to the first end of the regenerator housing and a second valve attached to the second end of the regenerator housing, the first valve and second valve each comprising a plurality of apertures spaced apart from each other along the circumferential direction with each aperture positioned adjacent to one of the pair of openings of one of the plurality of chambers;

a magnetic element positioned proximate to the regenerator housing and extending along the axial direction, the magnetic element creating a magnetic field, the magnetic element positioned so that a subset of the plurality of stages are moved within the magnetic field as the regenerator housing is rotated about the axial direction; and

a pair of seals comprising a first seal positioned adjacent to the first valve and a second seal positioned adjacent to the second valve such that the regenerator housing and the pair of valves are rotatable relative to the pair of seals, the first seal comprising the first inlet port and the first outlet port, the second seal comprising the second inlet port and a second outlet port,

wherein the first inlet port and the first outlet port are positioned in an opposing manner about the first seal and second inlet port and the second outlet port are positioned in an opposing manner about the second seal,

wherein the first inlet port and the second outlet port are positioned for fluid communication with the pair of openings of at least one chamber at a time as the regenerator housing is rotated about the axial direction so that heat transfer fluid from the first heat exchanger may receive heat from the stage of magneto caloric material located in the at least one chamber, and

wherein the second inlet port and the first outlet port are positioned for fluid communication with the pair of openings of at least one other chamber at a time as the regenerator housing is rotated about the axial direction so that heat transfer fluid from the second heat exchanger may deliver heat to the magneto caloric material in the at least one other chamber.

12. The refrigerator appliance of claim **11**, wherein the regenerator housing defines a radial direction and further comprises a cavity positioned radially-inward of the plurality of chambers, wherein the magnetic element is positioned within the cavity of the regenerator housing.

13. The refrigerator appliance of claim **12**, wherein the magnetic element comprises a plurality of magnets arranged in the shape of an arc and configured to project a magnetic field substantially along a radially-outward direction.

14. The refrigerator appliance of claim **13**, wherein the arc formed by the plurality of magnets extends about the circumferential direction by an amount in the range of about 170 degrees to about 190 degrees.

15. The refrigerator appliance of claim **14**, wherein the plurality of magnets are arranged in a HalBach array.

16. The refrigerator appliance of claim **11**, wherein the regenerator housing defines a radial direction and further comprises a cavity positioned radially-inward of the plurality of chambers, and wherein the magnetic element further comprising a first plurality of magnets positioned within the cavity and a second plurality of magnets positioned radially outward of the regenerator housing.

17. The refrigerator appliance of claim **11**, wherein the pair of ports on each of the pair of seals are positioned about the circumferential direction within a range of about 170 degrees to about 190 degrees from each other.

18. The refrigerator appliance of claim **11**, wherein each stage of the plurality of stages comprises a plurality of zones of magneto caloric material arranged sequentially along the axial direction, wherein each zone comprises magneto caloric material having a different temperature range over which a change in the magnetic moments of the magneto caloric material occurs as compared to an adjacent zone.

19. The refrigerator appliance of claim **18**, wherein the plurality of zones are arranged along the axial direction so that the temperature range over which the change in the magnetic moments of magneto caloric material occurs increases sequentially from zone to zone along the axial direction.

20. The refrigerator appliance of claim **11**, further comprising a motor in mechanical communication with the regenerator housing and configured for rotating the regenerator housing about the axial direction.

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