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(54) MAGNETIC REFRIGERATION CONTROL SYSTEM, AND METHOD THEREOF

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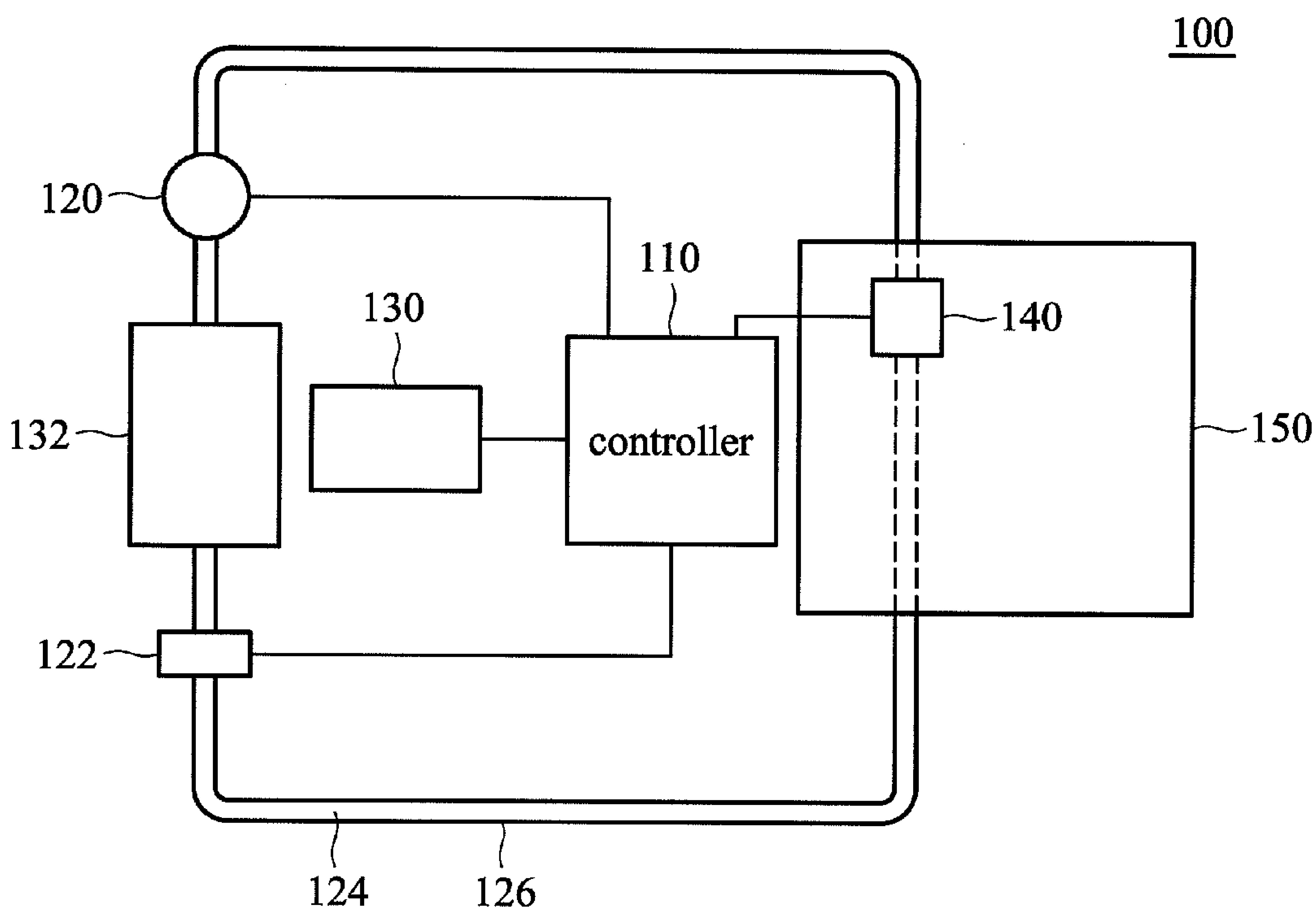
(57) **ABSTRACT**

A magnetic refrigeration control system, includes: a first magnetocaloric bed; a pipe, arranged through the first magnetocaloric bed; a coolant, flowing in the pipe; a pump, driving the coolant with a pumping speed; a valve, adjusting a flow period of the flowing coolant; a magnetic module, providing an increasing magnetic field to the first magnetocaloric bed during a magnetization period and providing a decreasing magnetic field to the first magnetocaloric bed during a demagnetization period; and a sensor, detecting a fluid pressure of the coolant flowing in the pipe, the temperature of a refrigerator, and a flowing rate of the coolant flowing in the pipe; and a controller, adjusting the pumping speed, the flow period, the magnetization period, and the demagnetization period according to the temperature, the fluid pressure, and the flowing rate in real time. A magnetic refrigeration control method is also disclosed.



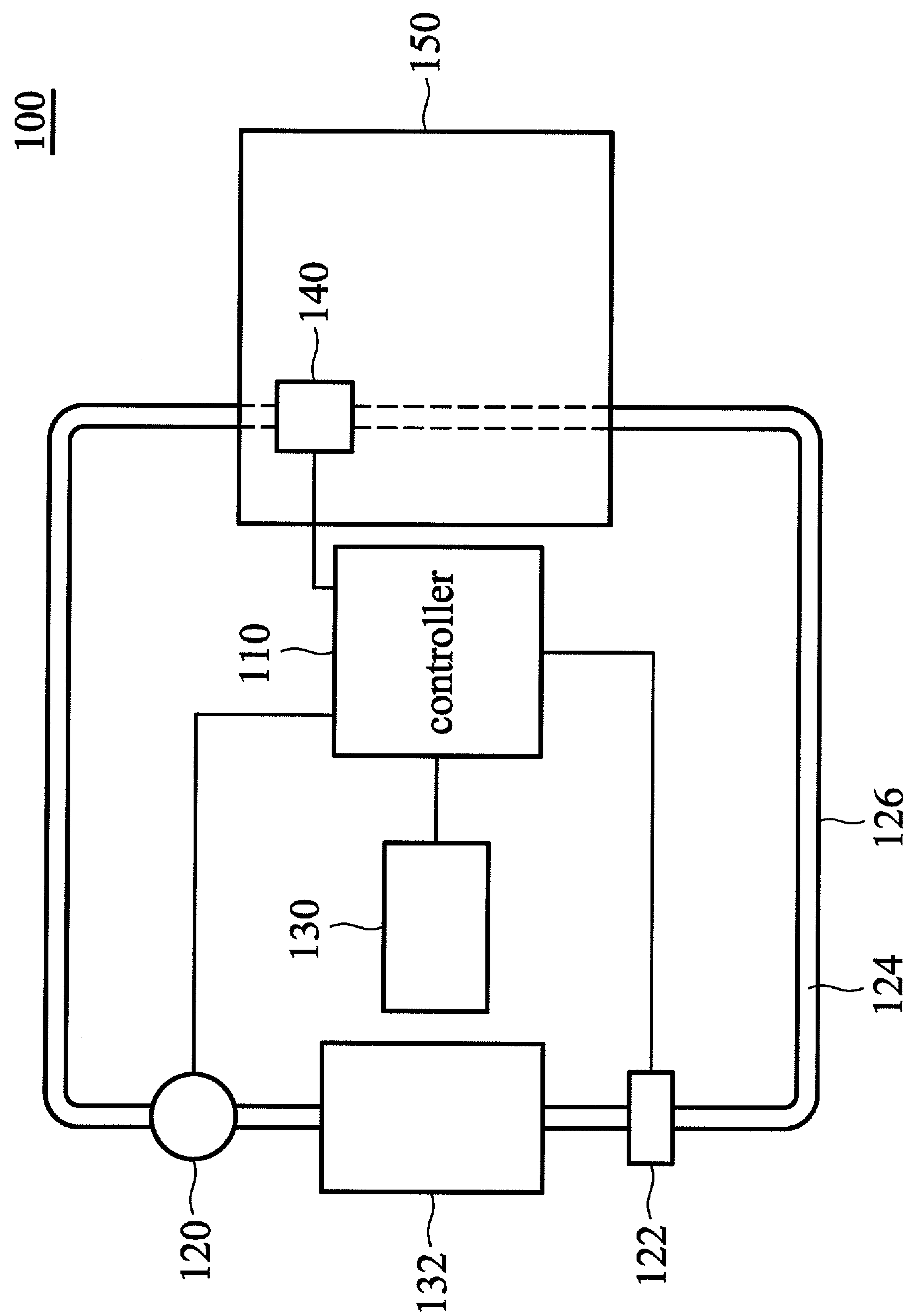


FIG. 1

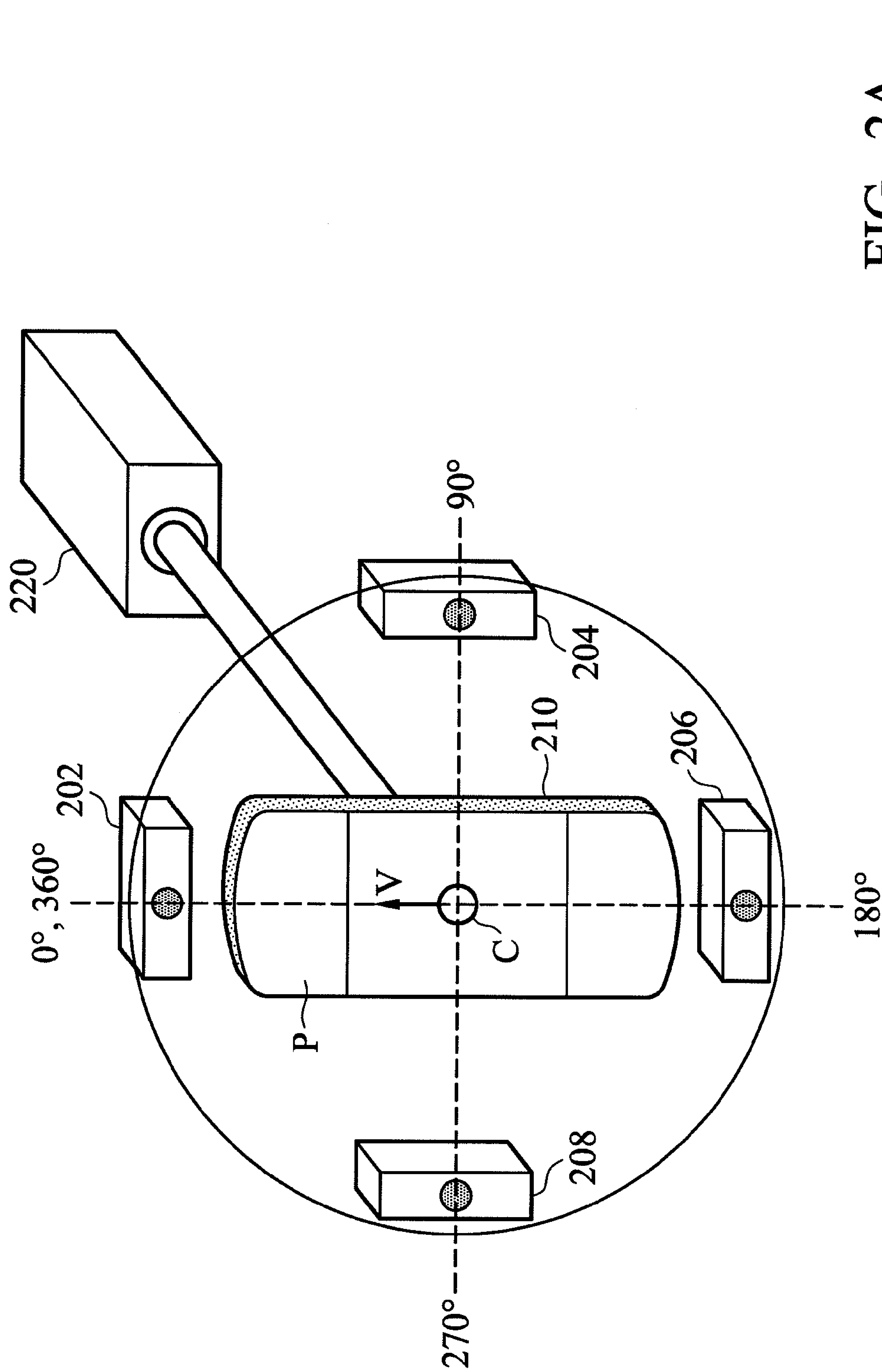


FIG. 2A

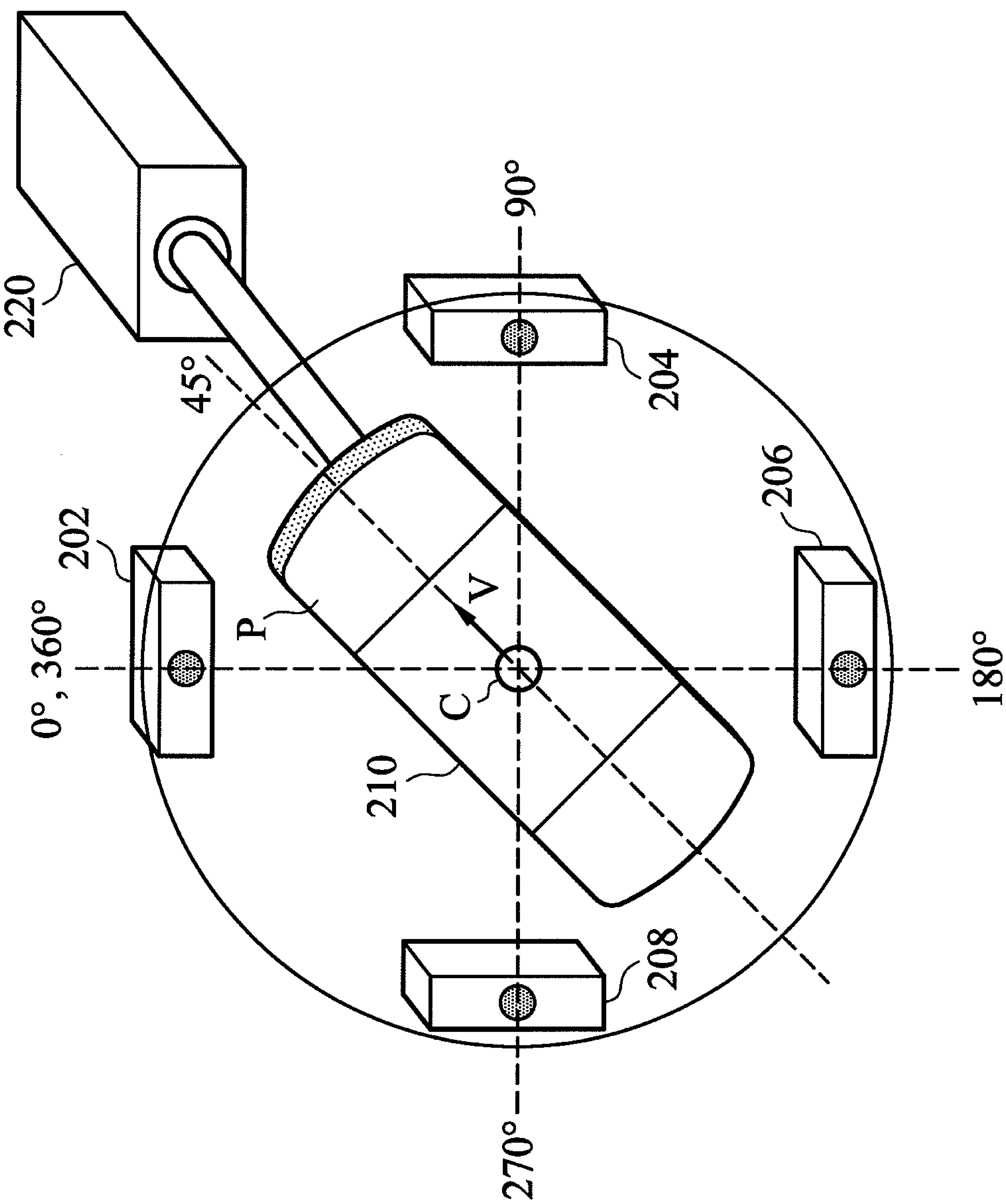


FIG. 2B

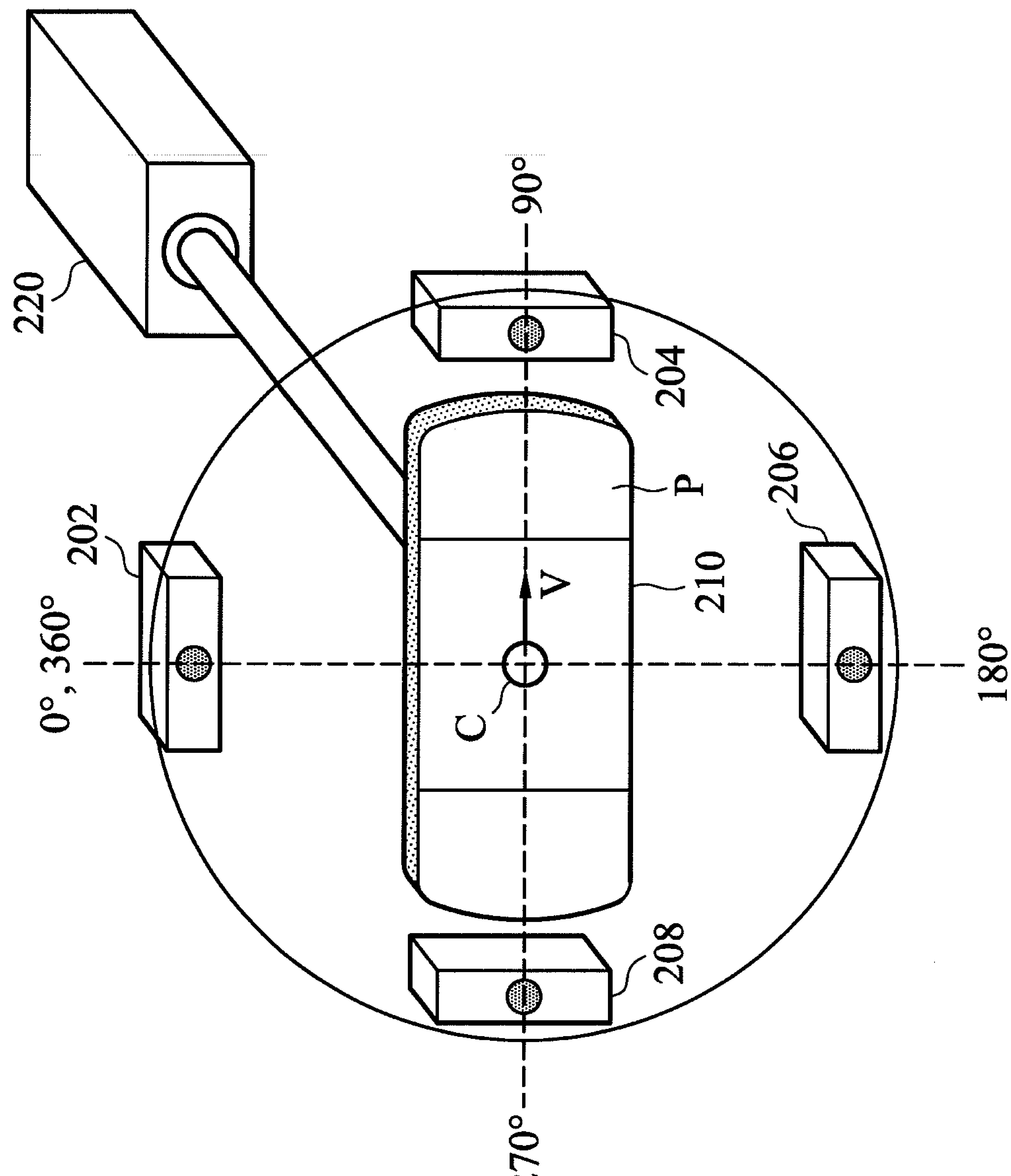


FIG. 2C

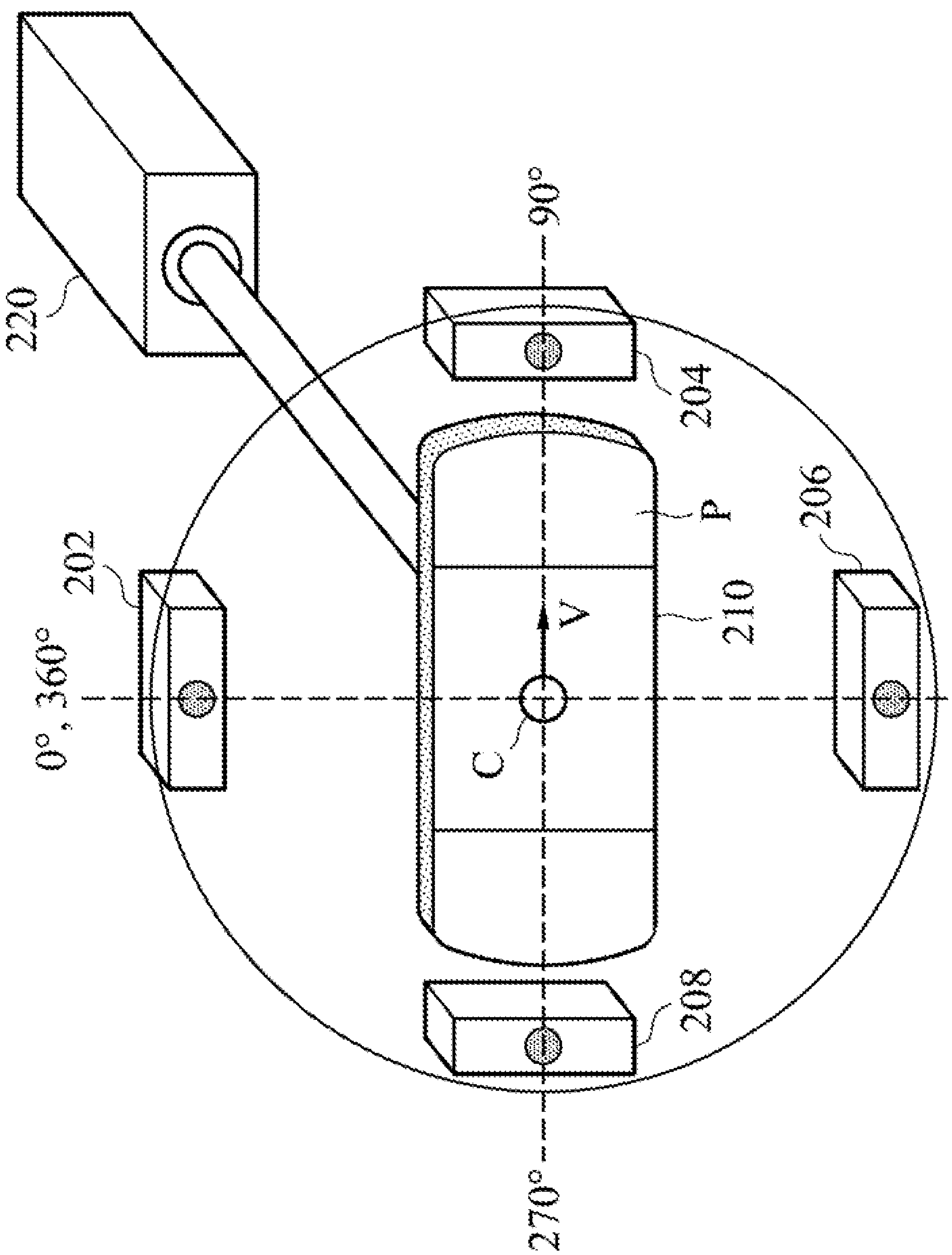


FIG. 2C

MAGNETIC REFRIGERATION CONTROL SYSTEM, AND METHOD THEREOF

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The disclosure relates generally to magnetic refrigeration technologies, and more particularly relates to the control of a magnetic refrigeration system with better cooling performance.

[0003] 2. Description of the Related Art

[0004] Present refrigeration technology, for example, a refrigerator, a freezer, a room air conditioner, a heat pump and the likes, mainly employs a gas compression/expansion cycle. However, a serious problem of environmental pollution is caused by specific Freon gases discharged into environment for refrigeration technology based on the gas compression/expansion cycle. Recently, magnetic refrigeration technology has been introduced as a highly efficient and environmentally friendly cooling technology. Magnetic refrigeration technology adapts a magnetocaloric effect (MCE) of magnetocaloric materials (MCM) to realize refrigeration cycles.

[0005] Nowadays, the operation frequency of the MCM based magnetic refrigeration system is fixed. For example, the frequency and cycle of magnetization or demagnetization to a magnetocaloric material are fixed. But, the cooling environment varies. Thus, for this kind of the magnetic refrigeration system is hard to achieve the best efficiency for various cooling situations or requirements.

BRIEF SUMMARY OF THE INVENTION

[0006] An embodiment of a magnetic refrigeration control system for an outer heat exchanger, includes: a first magnetocaloric bed; a pipe, arranged through the first magnetocaloric bed; a coolant, flowing in the pipe; a pump, driving the coolant with a pumping speed; a valve, adjusting a flow period of the coolant flowing in the pipe; a magnetic module, providing an increasing magnetic field to the first magnetocaloric bed during a magnetization period, and providing a decreasing magnetic field to the first magnetocaloric bed during a demagnetization period; a sensor, detecting a fluid pressure of the coolant flowing in the pipe, the temperature of the outer heat exchanger, and a flowing rate of the coolant flowing in the pipe; and a controller, adjusting the pumping speed, the flow period, the magnetization period, and the demagnetization period according to the temperature, the fluid pressure, and the flowing rate.

[0007] An embodiment of a magnetic refrigeration control method for cooling an heat exchanger, includes steps of: providing a magnetic refrigeration control system comprising a first magnetocaloric bed; a pipe arranged through the first magnetocaloric bed, and a coolant flowing in the pipe; driving the coolant with a pumping speed; adjusting a flow period of the coolant flowing in the pipe; providing an increasing magnetic field to the first magnetocaloric bed during a magnetization period, and providing a decreasing magnetic field to the first magnetocaloric bed during a demagnetization period; and detecting a fluid pressure of the coolant flowing in the pipe, the temperature of the outer heat exchanger, and a flowing rate of the coolant flowing in the pipe; adjusting the pumping speed, the flow period, the magnetization period, and the demagnetization period according to the temperature, the fluid pressure, and the flowing rate, wherein the temperature of the outer heat exchanger is determined by pumping speed, the flow period, the magnetization period and the demagnetization period.

BRIEF DESCRIPTION OF DRAWINGS

[0008] The invention will become more fully understood by referring to the following detailed description with reference to the accompanying drawings, wherein:

[0009] FIG. **1** is a schematic diagram illustrating an embodiment of magnetic refrigeration control system of the disclosure;

[0010] FIGS. **2**A-**2**C are schematic diagrams illustrating an embodiment of a magnetic module for proving magnetic field to magnetocaloric beds of the magnetic refrigeration control system shown in FIG. **1**.

DETAILED DESCRIPTION OF THE INVENTION

[0011] The making and using of the embodiments of the present invention are discussed in detail below. It should be appreciated, however, that the embodiments provide many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific ways to make and use the invention, and do not limit the scope of the invention.

[0012] FIG. **1** is a schematic diagram illustrating an embodiment of magnetic refrigeration control system of the disclosure. The magnetic refrigeration control system **100** comprises at least a controller **110**, a pump **120**, a valve **122**, a coolant **124**, a pipe **126**, a magnetic module **130**, a magnetocaloric bed **132**, a sensor **140**, and an outer heat exchanger **150**. The pump **120** and the valve **122** are connected by the pipe **126**, and the coolant **124** flows within the pipe **126**. In order to circulate the coolant **124**, the pipe **126** is constructed as a circulating pipe for example. The pump **120** drives the coolant **124** to flow, and the valve **122** adjusts the duration period of the flowing of the coolant **124** and the flowing rate of the coolant **124**. Also, the pipe **126** is arranged between the magnetocaloric bed **132** and the outer heat exchanger **150**. Therefore, the magnetocaloric bed **132** and the outer heat exchanger **150** can exchange heat with the coolant **124** flowing within the pipe **126**.

[0013] The magnetocaloric bed **132** contains magnetocaloric materials (MCM). In an embodiment, when magnetocaloric material is provided with a magnetic field or an increasing magnetic field, magnetocaloric material will heat up. While the magnetic field is held constantly, the coolant **124** is provided to take away heat generated from the magnetocaloric materials. And once the magnetocaloric material is sufficiently cooled down, the magnetic field is removed or largely decreased. Finally, due to its nature of having magnetocaloric effect (MCE), the magnetocaloric material cools down. On the other hand, the coolant **124** also takes away heat from the outer heat exchanger **150** when the magnetocaloric material cools down. Due to these features, magnetocaloric refrigeration is realized. The outer heat exchanger here may be heat sink, or similar devices which can exchange heat with the coolant **124** as here described or other heat exchanging media.

[0014] In an embodiment, the operations of the pump **120**, the valve **122**, and the magnetic module **130** are controlled by the controller **110**. For example, the controller **110** can adjust the pumping speed of the pump **120**, can open or close the valve **122**, and can adjust the strength or the duration period of the magnetic field provided by the magnetic module **130**.

[0015] It should be noted, the cooling performance and cooling temperature gradient (the speed of temperature spreading) of magnetocaloric refrigeration depend on the material characteristics inside the magnetocaloric bed **132**, the duration period of the increasing magnetic field provided to the magnetocaloric bed **132**, the duration period of the decreasing magnetic field provided to the magnetocaloric bed **132**, the variation of the magnetic field provided to the magnetocaloric bed **132**, the fluid pressure of the coolant **124** in the pipe **126**, and the flowing rate of the coolant **124** in the pipe **126**, etc. In order to perform better cooling power or establish the cooling temperature gradient faster, in some embodiments, the sensor **140** detects working and/or environment factors such as the fluid pressure of the coolant **124** in the pipe **126**, the flowing rate of the coolant **124** in the pipe **126**, and the temperature of the outer heat exchanger **150**. And then the controller **110** adjusts the pumping speed of the pump **120**, the open duration period of the valve **122**, the duration period of the increasing magnetic field generated by the magnetic module **130** and provided to the magnetocaloric bed **132**, and the duration period of the decreasing magnetic field generated by the magnetic module **130** and provided to the magnetocaloric bed **132**, according to the parameters, such as the temperature, the fluid pressure, and the flowing rate, obtained by the sensor **140**. By feeding back these parameters from the sensor **140** to the controller **110** in real time, the controller **110** can improve the cooling power or build up temperature gradient faster. It should be known, that the margin of adjusting the pumping speed of the pump **120**, the open duration period of the valve **122**, the duration period of the increasing magnetic field generated by the magnetic module **130** and provided to the magnetocaloric bed **132**, and the duration period of the decreasing magnetic field generated by the magnetic module **130** and provided to the magnetocaloric bed **132**, are all dependent on user requirements and designs.

[0016] While the magnetic refrigeration control system has been described by way of example and in terms of a brief embodiment, it is to be understood that the magnetic refrigeration control system can have not just one pump, valve, pipe, magnetocaloric bed, outer heat exchanger, and/or magnetic module, however, arrangement of the magnetic refrigeration control system depends described here on requirements or designs. Also, the arrangement of the pump, valve, pipe, magnetocaloric bed, outer heat exchanger, and/or magnetic module is not limited to that described above.

[0017] FIG. 2A-2C are schematic diagrams illustrating an embodiment of a magnetic module and magnetocaloric beds for the magnetic refrigeration control system shown in FIG. **1**. Refer to FIGS. **1**, 2A, 2B, and 2C, the magnetic module **130** comprises a magnet **210** and a driving means **220**, and the driving means **220** is controlled by the controller **110**. The axle center C of the magnet **210** is connected to the driving means **220**. Thus, the driving means **220** drives the magnet **210** to rotate via the power provided from the controller **110**. The magnet **210** described above may be a permanent magnet, a super conductor based magnet, or a set of electro-coils with an outer electrical circuit, and in this embodiment, the magnet **210** is a permanent magnet, but is not to limit this invention.

[0018] In this embodiment, four magnetocaloric beds **202**, **204**, **206**, and **208** are arranged beside the magnet **210**. A vector V represents the direction from the axle center C to the magnetic pole P of the magnet **210**. When the magnetic pole P rotates to a 0 degree angle, the vector V points to the magnetocaloric bed **202**. When the magnetic pole P then rotates to a 90 degree angle, the vector V points to the magnetocaloric bed **204**. When the magnetic pole P then rotates to a 180 degree angle, the vector V points to the magnetocaloric bed **206**. When the magnetic pole P then rotates to a 270 degree angle, the vector V points to the magnetocaloric bed **208**. When the magnetic pole P then further rotates to a 360 degree angle, the vector V points to the magnetocaloric bed **202** again, i.e. the magnetic pole P rotates for a complete circle and finally back to its original position where is also at 0 degree. Thus, when the driving means **220** drives the magnetic pole P to rotate from a 0 degree angle to 90 degree angle, viewed as aspects of the magnetocaloric beds **202** and **204**, an increasing magnetic field is provided to the magnetocaloric bed **204** by relatively rotating of the magnet **210**, and a decreasing magnetic field is provided to the magnetocaloric bed **202** by relatively rotating of the magnet **210**. It should be known, that the driving means **220** can drive the magnetic pole P to rotate from a 90 degree angle back to 0 degree angle. Accordingly, viewed as aspects of the magnetocaloric beds **202** and **204**, a decreasing magnetic field is provided to the magnetocaloric bed **204** by relatively rotating of the magnet **210**, and an increasing magnetic field is provided to the magnetocaloric bed **202** by relatively rotating of the magnet **210**.

[0019] Also, different variation rates and/or quantity of the magnetic field provided to the magnetocaloric bed cause different performances and cooling gradients for magnetocaloric refrigeration. Thus, the controller **110** can adjust a driving means operation frequency of the driving means **220**, in order to perform a proper cooling gradient corresponding to user requirements or designs.

[0020] In some embodiments, when rotating the magnetic pole P from a 0 degree angle to 90 degree angle, the driving means **220** only drives the magnetic pole P to rotate to a proper degree of angle larger than a 45 degree angle (such as 45.1, 46, or 50 degrees, . . . etc), as shown in FIG. 2B. When the magnetic pole P reaches a determined degree angle, the driving means **220** stops driving the magnet **210** from rotating, namely the controller **110** stops providing the power or reducing the power to the driving means **220** at this time. Due to the magnetocaloric beds **202**, **204**, **206**, and **208** containing of magnetocaloric materials which is basically magnetic contractive, and wherein the distance between the magnetic pole P and the magnetocaloric bed **204** is less than the distance between the magnetic pole P and the magnetocaloric bed **202**, the magnetic pole P will rotate to a 90 degree angle automatically by the magnetic attraction force between the magnetic pole P and the magnetocaloric bed **204**, as shown in FIG. 2C. When the magnet **210** requires rotating, or a decreasing magnetic field is required to be provided to the magnetocaloric bed **204**, the driving means **220** will start to drive the magnet **210** to rotate. Due to the magnet **210** rotates automatically such that the driving means **220** not being required to be provided power all the time, the total consumption of power can be further reduced.

[0021] Those who are skilled in this technology field can delete, add, or change the arrangement of the magnetocaloric bed, magnet, and/or driving means described above without departing from the scope and spirit of this invention. For example, there can be eight magnetocaloric beds in the magnetic refrigeration control system, and the magnetocaloric beds may be arranged in a circular path with the axle center C as a center, wherein the eight magnetocaloric beds are disposed at 0, 45, 90, 135, 180, 225, 270, and 315 degree angles respectively. Thus, when rotating the magnetic pole P from a 0 degree angle to 45 degree angle, the driving means **220** can drive the magnetic pole P to rotate to a degree angle just larger than a 22.5 degree angle.

[0022] While the invention has been described by way of example and in terms of preferred embodiment, it is to be understood that the invention is not limited thereto. Those who are skilled in this technology can still make various alterations and modifications without departing from the scope and spirit of this invention. Therefore, the scope of the present invention shall be defined and protected by the following claims and their equivalents.

What is claimed is:

1. A magnetic refrigeration control system for cooling an outer heat exchanger, comprising:
- a first magnetocaloric bed;
- a pipe arranged through the first magnetocaloric bed;
- a coolant flowing in the pipe;
- a pump, driving the coolant with a pumping speed;
- a valve, adjusting a flow period of the coolant flowing in the pipe;
- a magnetic module, providing an increasing magnetic field to the first magnetocaloric bed during a magnetization period, and providing a decreasing magnetic field to the first magnetocaloric bed during a demagnetization period;
- a sensor, detecting a fluid pressure of the coolant flowing in the pipe, the temperature of the outer heat exchanger, and a flowing rate of the coolant flowing in the pipe; and
- a controller, adjusting the flow period, the pumping speed, the magnetization period, and the demagnetization period according to the temperature, the fluid pressure, and the flowing rate in real time.

2. The magnetic refrigeration control system of claim **1**, wherein the magnetic module has a magnet and a driving means controlled by the controller, wherein the driving means shifts the magnet towards the first magnetocaloric bed for providing the increasing magnetic field to the first magnetocaloric bed, and the driving means shifts the magnet away from the first magnetocaloric bed for providing the decreasing magnetic field to the first magnetocaloric bed.

3. The magnetic refrigeration control system of claim **2**, further comprising a second magnetocaloric bed, wherein the controller provides a power to the driving means, the driving means shifts the magnet to a position according to the power, and the distance between the first magnetocaloric bed and the position is larger than the distance between the second magnetocaloric bed and the position, and the controller cuts off or reduces the power providing to the driving means when the magnet reaches to the position.

4. The magnetic refrigeration control system of claim **3**, wherein the first magnetocaloric bed and the second magnetocaloric bed contain magnetocaloric materials, the magnetocaloric materials are heated up when the increasing magnetic field is provided, and the magnetocaloric materials are cooled down when the decreasing magnetic field is provided.

5. The magnetic refrigeration control system of claim **2**, wherein a driving means operation frequency of the driving means is determined by the controller according to the temperature, the fluid pressure, and the flowing rate.

6. A magnetic refrigeration control method for cooling an outer heat exchanger, comprising steps of:
- providing a magnetic refrigeration control system comprising a first magnetocaloric bed, a pipe arranged through the first magnetocaloric bed, and a coolant flowing in the pipe;
- driving the coolant with a pumping speed;
- adjusting a flow period of the coolant flowing in the pipe;
- providing an increasing magnetic field to the first magnetocaloric bed during a magnetization period, and
- providing a decreasing magnetic field to the first magnetocaloric bed during a demagnetization period;
- detecting a fluid pressure of the coolant flowing in the pipe, the temperature of the outer heat exchanger, and a flowing rate of the coolant flowing in the pipe; and
- adjusting the pumping speed, the flow period, the magnetization period, and the demagnetization period according to the temperature, the fluid pressure, and the flowing rate in real time,
- wherein the temperature of the outer heat exchanger is determined by the pumping speed, the flow period, the magnetization period and the demagnetization period.

7. The magnetic refrigeration control method of claim **6**, further comprising:
- shifting a magnet towards the first magnetocaloric bed for providing the increasing magnetic field; and
- shifting the magnet away from the first magnetocaloric bed for providing the decreasing magnetic field.

8. The method of claim **7**, further comprising:
- shifting the magnet to a position by providing a power to a driving means, wherein the distance between the position and the first magnetocaloric bed is larger than the distance between the position and a second magnetocaloric bed; and
- cutting off or reducing the power providing to the driving means when the magnet reaches to the position.

9. The method of claim **8**, wherein a driving means operation frequency of the driving means is determined according to the temperature, the fluid pressure, and the flowing rate.

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