

MAGNETOCALORIC THERMAL GENERATOR AND METHOD FOR COOLING SAME

Technical scope:

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The invention relates to a magnetocaloric thermal generator comprising at least one primary circuit fluidically connecting magnetocaloric elements by means of a heat transfer fluid called primary fluid flowing alternately back and forth, said magnetocaloric elements being subjected to the variable magnetic field of a magnetic system that creates alternately in each magnetocaloric element a magnetic heating phase and a magnetic cooling phase, generator wherein the primary circuit comprises a cold side and a hot side at which magnetocaloric elements are fluidically connected with each other.

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It also relates to a method for cooling a fluid called secondary fluid by a magnetocaloric thermal generator.

Prior art:

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Magnetic refrigeration technology at ambient temperature has been known for more than thirty years and the advantages it provides in terms of ecology and sustainable development are widely acknowledged. Its limits in terms of its useful calorific output and its efficiency are also well known. Consequently, all the research undertaken in this field tends to improve the performances of such a generator, by adjusting the various parameters, such as the magnetization power, the performances of the magnetocaloric element, the exchange surface between the heat transfer fluid and the magnetocaloric elements, the performances of the heat exchangers, etc.

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These thermal generators use the magnetocaloric effect (MCE) of certain materials, which consists in a variation of their temperature when they are subjected to a

variable magnetic field. In such generators, the magnetocaloric materials are subjected to a succession of magnetic magnetization and demagnetization phases and a heat exchange is performed with a heat transfer fluid called primary fluid in order to collect the thermal energy produced by said materials and achieve the widest temperature variation possible in these materials (temperature gradient). For that purpose, the circulation of the primary fluid is alternated and this primary fluid circulates in channels or pores passing through the magnetocaloric material. A magnetocaloric cycle comprises two phases, that is to say a magnetization phase and a demagnetization phase, which translate in energy available at every phase. This cycle is repeated up to frequencies of several Hertz. During these phases, the primary fluid flows through the magnetocaloric material and will either heat up at the contact of the material during a so-called magnetization phase, or cool down at the contact of the material during a so-called demagnetization phase. The magnetocaloric effect, which corresponds to an entropy variation of said material, is maximal when the temperature of the material is close to its Curie temperature.

Now, a magnetocaloric thermal generator must be able to exchange the thermal energy it produces with at least one external application. This exchange is generally achieved by one or several heat exchangers with the objective of restituting to or exchanging with one or several applications, which are external to said magnetocaloric thermal generator, the thermal energy produced by said thermal generator. These external applications can be the air surrounding the thermal generator, a thermal device or enclosure, for example.

In a classical configuration, the magnetocaloric elements of a magnetocaloric thermal generator are connected to each other on the hot side by means of a heat exchanger and, symmetrically, they are also connected to each other on the cold side by means of another heat exchanger. However, experience has shown that such configuration has limitations.

This is especially the case when the cold side of the generator is exploited. The fact of performing a heat exchange with an application or a secondary circuit showing a great temperature difference with respect to the temperature of the primary fluid results in considerable heating of the cold side of the generator and degradation of its thermal efficiency. In other words, the thermal gradient established in the thermal generator is degraded, so that a part of the output produced by the magnetocaloric effect must be used to restore this gradient and, consequently, this part of the output cannot be exploited or used by the external application(s).

Likewise, when the hot side of the thermal generator is exploited, there is a risk of cooling the hot side of the generator and of degrading its thermal efficiency.

To exploit optimally the output of a thermal generator, it is thus necessary to optimize the heat exchange characteristics between the primary circuit and the secondary circuit.

Description of the invention:

The present invention aims to overcome these disadvantages by offering a solution to the above-mentioned problems. To that purpose, the magnetocaloric thermal generator according to the invention is designed so as to optimize the thermal energy transfer between the thermal generator and the external application(s) to be refrigerated, cooled or heated, in order to have the lowest possible impact on the thermal gradient established in the magnetocaloric thermal generator and on its thermal output. Another subject of the invention is a magnetocaloric thermal generator particularly suitable for continuous cooling of a fluid circulating in a secondary circuit.

To that purpose, this invention offers a magnetocaloric thermal generator of the kind described in the preamble, characterized in that at least one of said hot and cold sides

of the primary circuit comprises at least one outlet point connected to another point of the primary circuit, called injection point, by means of at least one bypass pipe allowing the primary fluid to be displaced only in one direction, only from the outlet point towards the injection point.

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In a preferred embodiment, the magnetocaloric elements can be distributed in at least two stages, and the magnetocaloric elements of one of said stages can be connected fluidically with each other on the cold side and the magnetocaloric elements of another of said stages can be connected fluidically with each other on the hot side.

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In a first variant, the magnetocaloric elements of two connected stages can be constantly in a reversed magnetic phase. In another variant, the magnetocaloric elements of two connected stages can be constantly in an identical magnetic phase.

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According to the invention, the bypass pipe can be thermally connected to a secondary circuit by at least one heat exchange zone.

Moreover, said heat exchange zone can be designed to achieve a counter-current, co-current or cross-current displacement between the primary fluid and a secondary fluid of said secondary circuit.

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The bypass line can advantageously comprise a device for adjusting the flow rate of the primary fluid that circulates in it.

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In an embodiment, said at least one outlet point is located in the cold side of the primary circuit. In this embodiment, the injection point can be located in the hot side of the primary circuit.

In a second embodiment, said at least one outlet point is located in the hot side of the primary circuit. In this embodiment, the injection point can be located in the cold side of the primary circuit.

- 5 In both embodiments, the injection point can be, as a variant, located between two stages of magnetocaloric elements.

In a further variant, the injection point can be located between consecutive magnetocaloric elements of each stage.

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This invention also offers a method for cooling a fluid called secondary fluid by means of a magnetocaloric thermal generator of the kind described in the preamble, characterized in that it consists in connecting thermally the secondary circuit in which the secondary fluid circulates by means of at least one heat exchange zone to a
15 bypass pipe of said magnetocaloric thermal generator and to have said secondary fluid circulating continuously in said secondary circuit.

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Such method is particularly suitable for achieving the cooling of a secondary fluid that is permanently renewed. So, this method is advantageous for cooling a secondary fluid that flows in a secondary circuit that does not loop back on itself and in which the hydraulic flow and the thermal flow of the secondary fluid are continuous.

Brief description of the drawings:

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The present invention and its advantages will be better revealed in the following description of the embodiments given as non limiting examples, in reference to the drawings in appendix, in which:

- figures 1A and 1B are schematic views of two stages of a thermal generator
30 according to a first embodiment variant, in opposite magnetic phases,

- figures 2A to 2B are schematic views of two stages of a thermal generator according to a second embodiment variant, in opposite magnetic phases,
- figures 3A and 3B are schematic views of two stages of a thermal generator according to a third embodiment variant, in opposite magnetic phases,
- 5 - figures 4A and 4B are schematic views of two stages of a thermal generator according to a fourth embodiment variant, in opposite magnetic phases,
- figures 5A and 5B are schematic views of two stages of a thermal generator according to a fifth embodiment variant, in opposite magnetic phases,
- figures 6A and 6B are schematic views of two stages of a thermal generator according to a sixth embodiment variant, in opposite magnetic phases,
- 10 - figures 7A and 7B are schematic views of two stages of a thermal generator according to a seventh embodiment variant, in opposite magnetic phases,
- figures 8A and 8B are schematic views of two stages of a thermal generator according to an eighth embodiment variant, in opposite magnetic phases,
- 15 - figure 9 is a simplified perspective view of the thermal generator comprising the two stages represented schematically in figures 7A and 7B,
- figures 10A and 10B are schematic views of two stages of a thermal generator according to a ninth embodiment variant, in opposite magnetic phases,
- figures 11A and 11B are schematic views of two stages of a thermal generator according to a tenth embodiment variant, in opposite magnetic phases, and
- 20 - figures 12A and 12B are schematic views of two stages of a thermal generator according to an eleventh embodiment variant, in opposite magnetic phases.

Illustrations of the invention:

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In the illustrated embodiment examples, the identical elements or parts have the same numerical references.

The invention relates to a magnetocaloric thermal generator 10, 20, 30, 40, 50, 60, 30 70, 80, 90, 100, 110 comprising magnetocaloric elements M_{11} , M_{12} , M_{21} , M_{22} , M_{111} ,

M₁₁₂, M₁₁₃, M₁₁₄, M₂₂₁, M₂₂₂, M₂₂₃, M₂₂₄. In the illustrated embodiment variants, these magnetocaloric elements M₁₁, M₁₂, M₂₁, M₂₂, M₁₁₁, M₁₁₂, M₁₁₃, M₁₁₄, M₂₂₁, M₂₂₂, M₂₂₃, M₂₂₄ are distributed in at least two thermal stages. A heat transfer fluid called primary fluid is displaced in an alternating movement in at least one primary circuit passing through said magnetocaloric elements M₁₁, M₁₂, M₂₁, M₂₂, M₁₁₁, M₁₁₂, M₁₁₃, M₁₁₄, M₂₂₁, M₂₂₂, M₂₂₃, M₂₂₄. The function of this primary fluid is, on the one hand, to establish and maintain a thermal gradient in the magnetocaloric elements of said thermal stages between two ends of thermal generator 10, 20, 30, 40, 50, 60, 70, 80, that is to say a cold side F and a hot side C and, on the other hand, to allow exchanging or restituting the thermal energy produced in said generator with at least one external application, that is to say not belonging to thermal generator 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110. This exchange or this restitution occurs by means of an exchange zone that can be materialized by a heat exchanger. This exchange zone allows achieving a heat exchange between the primary fluid and a secondary fluid of a secondary circuit that belongs to the external application.

Even though this is not illustrated, the invention also provides to have only one stage of magnetocaloric elements.

The primary fluid and the secondary fluid are preferably liquids. The secondary fluid is preferably displaced continuously by a pump or any similar device for cooling, heating or tempering an external application. The primary fluid intended to be in contact with the magnetocaloric elements can be made of water, water with an antifreeze product such as glycol for example, a liquid gas, pressurized or not, or a brine.

Each magnetocaloric element M₁₁, M₁₂, M₂₁, M₂₂, M₁₁₁, M₁₁₂, M₁₁₃, M₁₁₄, M₂₂₁, M₂₂₂, M₂₂₃, M₂₂₄ can be made of one or several magnetocaloric materials through which the primary fluid can flow. For the purpose of this invention, a magnetocaloric element must be understood as a physical element comprising magnetocaloric

material. A magnetocaloric element can in particular comprise several types of magnetocaloric materials. To that purpose, said magnetocaloric elements can be porous so that their pores form through fluid passages. They can also have the form of one or several solid blocks in which mini or micro channels are machined, molded or injected. They can also be made of an assembly of superposed, possibly grooved plates, between which the heat transfer fluid can flow. They can finally have the form of powder or particles, so that the gaps form fluid passages. Any other embodiment allowing the primary fluid to achieve heat exchange with the material making up a magnetocaloric element M_{11} , M_{12} , M_{21} , M_{22} , M_{111} , M_{112} , M_{113} , M_{114} , M_{221} , M_{222} , M_{223} , M_{224} can of course be suitable. The magnetocaloric materials making up magnetocaloric elements M_{11} , M_{12} , M_{21} , M_{22} , M_{111} , M_{112} , M_{113} , M_{114} , M_{221} , M_{222} , M_{223} , M_{224} have preferably different Curie temperatures, going from the lowest towards the highest from cold side F towards hot side C.

In the represented embodiment variants, the magnetic system that subjects magnetocaloric elements M_{11} , M_{12} , M_{21} , M_{22} , M_{111} , M_{112} , M_{113} , M_{114} , M_{221} , M_{222} , M_{223} , M_{224} to a magnetic field variation comprises permanent magnets 2 or similar (figure 9), and is moved with respect to said magnetocaloric elements M_{11} , M_{12} , M_{21} , M_{22} , M_{111} , M_{112} , M_{113} , M_{114} , M_{221} , M_{222} , M_{223} , M_{224} to create alternately in said magnetocaloric elements M_{11} , M_{12} , M_{21} , M_{22} , M_{111} , M_{112} , M_{113} , M_{114} , M_{221} , M_{222} , M_{223} , M_{224} a heating phase when a magnetic field is applied or increased, then a cooling phase when the magnetic field is removed or decreased. This magnetic system can also have the form of a sequentially powered electromagnet or of any other similar means liable to generate a magnetic field variation. The inversions of the direction of circulation of the primary fluid in the primary circuit are synchronized with the magnetization and demagnetization phases of magnetocaloric elements M_{11} , M_{12} , M_{21} , M_{22} , M_{111} , M_{112} , M_{113} , M_{114} , M_{221} , M_{222} , M_{223} , M_{224} , in order to establish the highest temperature gradient possible in magnetocaloric elements M_{11} , M_{12} , M_{21} , M_{22} , M_{111} , M_{112} , M_{113} , M_{114} , M_{221} , M_{222} , M_{223} , M_{224} . To that purpose, the primary fluid passing through a magnetocaloric element in heating phase – that is

to say magnetized – is displaced towards hot side C and is then displaced towards cold side F when it passes through a magnetocaloric element in cooling phase – that is to say demagnetized. The direction of circulation of the primary fluid is represented by arrows in the attached figures.

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Figure 1 thus represents a primary circuit P_{10} connecting two stages E_1 , E_2 of a magnetocaloric thermal generator 10 according to a first embodiment variant of the invention. The primary circuit connects the two stages E_1 , E_2 and comprises two actuators 3 displacing the primary fluid in an alternating back and forth movement.

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Primary circuit P_{10} thus comprises two parallel branches of the primary fluid circuit passing through said magnetocaloric elements and connected to each other on hot side C and on cold side F. The magnetic system is illustrated by permanent magnets 2. The two stages E_1 and E_2 are connected through actuators 3, which are for example pistons moved by a profile of a mobile control cam. Such pistons can be rigid or deformable such as for example a membrane. Of course, any other means able to displace the primary fluid may be used. Moreover, the displacement of a piston or similar can be controlled by an operating device that can be a control cam, a magnetic device, a linear motor or any equivalent means able to move said actuator back and forth.

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Moreover, magnetocaloric elements M_{11} , M_{12} of stage E_1 are connected on cold side F of primary circuit P_{10} and magnetocaloric elements M_{21} , M_{22} of stage E_2 are connected on hot side C of primary circuit P_{10} . According to the invention, cold side F of primary circuit P_{10} comprises an outlet point S_1 fluidically connected by a bypass pipe D_1 to an injection point I_1 in hot side C of said primary circuit P_{10} . This bypass pipe D_1 comprises a device that only allows the fluid to pass from outlet point S_1 towards injection point I_1 . Such device controlling the direction of circulation of the primary fluid can be for example a check valve 4. This bypass pipe D_1 passes through a cold exchange zone Z_{F1} where the primary fluid performs a heat exchange with a secondary fluid of a secondary circuit 6.

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So, the fact of forcing the direction of circulation of the fluid in bypass pipe D_1 allows making sure that only the fluid exiting cold side F of a magnetocaloric element in a demagnetization phase can be directed towards this bypass pipe D_1 .
 5 From this results that the cooling capacity of the secondary circuit is optimized.

The primary fluid coming from bypass pipe D_1 has heated up after having passed through cold exchange zone Z_{F1} . It is however reinjected in hot side C of primary circuit P_{10} , so that this heating has a limited impact on the temperature of cold side F
 10 of primary circuit P_{10} , which is particularly advantageous in the case of refrigeration. This moreover allows achieving a substantial exchange in cold exchange zone Z_{F1} .

This embodiment variant is also transposable to an embodiment with one single stage, in which the bypass pipe can connect an outlet point of the cold side to an
 15 injection point of the hot side of the primary circuit.

Primary circuit P_{10} comprises two consecutive hot exchange zones Z_{C1} , Z_{C2} on its hot side C, and injection point I_1 is located between these two exchange zones Z_{C1} , Z_{C2} . This is very advantageous as this allows injecting the primary fluid coming from
 20 bypass pipe D_1 in the portion of primary circuit P_{10} that passes through a magnetocaloric element in cooling phase. Thus the primary fluid is reinjected towards magnetocaloric element M_{22} , which is cooling down in the phase illustrated in figure 1A and is reinjected in magnetocaloric element M_{21} , which is cooling down in the following or opposite magnetic phase illustrated in figure 1B. This also allows
 25 furthering the mixing of the fluids at injection point I_1 .

The hot exchange zones Z_{C1} , Z_{C2} allow either evacuating the heat produced by thermal generator 10, or heating up another external application, for example by means of a heat exchange with a second secondary fluid circuit 7.

According to the invention, bypass line D_1 can advantageously comprise a flow rate adjusting device 5 for the primary fluid that circulates in it. This adjusting device 5 allows determining the heat exchange capacity between primary circuit P_{10} and secondary circuit 6 in cold exchange zone Z_{F1} and adjusting the head losses between primary circuit P_{10} and bypass pipe D_1 . This characteristic can be transposed to all embodiment variants represented.

Moreover, in all illustrated examples, the outlet points are located in cold side F of the primary circuit and therefore illustrate magnetocaloric thermal generator configurations optimized for optimal use of their cold output. The invention also provides to position these outlet points in the hot side and to perform a classical exchange in cold side F. Such arrangement allows exploiting the heat produced by the thermal generator while limiting the impact due to this heat exchange on the temperature of hot side C of the primary circuit, which is particularly advantageous in the case of heating. This therefore allows achieving a significant exchange in the exchange zone connected to the bypass pipe whose outlet point is located in the hot side of the primary circuit. In other words, the whole of the illustrated examples can be transposed by inverting hot side C and cold side F in order to obtain a higher capacity to heat or to increase the temperature of a secondary fluid of an external application.

Figures 2A and 2B represent an embodiment variant of a primary circuit P_{20} of a magnetocaloric thermal generator 20 that differs from the one represented in figures 1A and 1B by its hot side C. In this variant, hot side C of primary circuit P_{20} comprises one single hot heat exchange zone Z_{C3} whose inlet and outlet form respectively an injection point I_2, I_3 . Bypass pipe D_2 divides into two pipe portions and these pipe portions comprise each a check valve. This also ensures that the primary fluid coming from bypass pipe D_2 is always reinjected towards magnetocaloric element M_{21}, M_{22} that is undergoing cooling. Such configuration with one single hot exchange zone Z_{C3} against two hot exchange zones Z_{C1} and Z_{C2}

in thermal generator 10 described previously allows simplifying the construction of thermal generator 20 and thus reducing its cost price.

Figures 3A and 3B represent another embodiment variant of a magnetocaloric thermal generator 30. In this variant, the generator comprises two bypass pipes D_3 , D_4 . Bypass pipe D_4 connects an outlet point S_2 of cold side F directly connected to a magnetocaloric element M_{11} of stage E_1 , cold side F, to an injection point I_5 of hot side C directly connected to a magnetocaloric element M_{22} of stage E_2 , hot side C, which is constantly in the same magnetization state as the other magnetocaloric element M_{11} , that is to say in cooling phase in figure 3A. Likewise, bypass pipe D_3 connects an outlet point S_3 of cold side F directly connected to a magnetocaloric element M_{12} of stage E_1 , cold side F, to an injection point I_4 of hot side C directly connected to a magnetocaloric element M_{21} of stage E_2 , hot side C, which is constantly in the same magnetization state as the other magnetocaloric element M_{12} , that is to say in heating phase in figure 3A. In such configuration and in the magnetization state illustrated in figure 3A, the primary fluid is cooled when it passes through magnetocaloric element M_{11} and follows bypass pipe D_4 passing through cold exchange zone Z_{F2} to be reinjected at injection point I_5 in magnetocaloric element M_{22} of stage E_2 , hot side C. The fact of reinjecting unidirectionally in hot side C primary fluid coming from cold side F that warmed up in cold heat exchange zone Z_{F2} allows, in the case where this reinjected fluid has a temperature slightly lower or colder than that of the primary fluid in hot side C, to achieve both cooling of magnetocaloric element M_{22} by thermal conduction / transfer with this reinjected fluid and cooling by the magnetocaloric effect due to the demagnetization. This can be equivalent to a pre-cooling of magnetocaloric element M_{22} . This can result in shifting downwards the thermal gradient in primary circuit P_{30} , between hot side C and cold side F, and thus in increasing the refrigeration capacity of thermal generator 30. In the magnetization state illustrated in figure 3A, there is no fluid displacement in second bypass pipe D_3 . Each bypass branch or pipe is independent, and its flow rate is adjustable separately.

Conversely, in the opposite magnetization state illustrated in figure 3B, there is no primary fluid displacement in first bypass pipe D_4 , while the primary fluid is in displacement in second bypass pipe D_3 passing through cold exchange zone Z_{F3} to be reinjected at injection point I_4 in magnetocaloric element M_{21} of stage E_2 , hot side C. The heat exchange on hot side C is achieved in a conventional way. The ends of the two magnetocaloric elements of stage E_2 , hot side C, are separated by a heat exchange zone Z_{C4} intended for evacuating the heat produced by thermal generator 30 or for heating another external application, for example by means of a heat exchange with a second secondary fluid circuit 7.

Figures 4A and 4B represent an embodiment variant of a magnetocaloric thermal generator 40 that differs from thermal generator 30 of the previous figures by the fact that injection points I_6 and I_7 of bypass pipes D_5 and D_6 are located between the two stages E_1 , E_2 . This arrangement is particularly advantageous in cases when the temperature of the primary fluid reinjected in primary circuit P_{40} corresponds or is liable to correspond to that of the primary fluid at injection point I_6 , I_7 located between the two stages E_1 , E_2 .

Figures 5A and 5B represent an embodiment variant of a magnetocaloric thermal generator 50 that differs from thermal generator 40 of previous figures 4A and 4B by the fact, on the one hand, that the stages comprise more magnetocaloric elements M_{111} , M_{112} , M_{113} , M_{114} , M_{221} , M_{222} , M_{223} , M_{224} and, on the other hand, that injection points I_8 and I_9 of bypass pipes D_7 and D_8 are located between the consecutive magnetocaloric elements M_{111} , M_{113} and M_{112} , M_{114} of stage E_{10} located on cold side F. This arrangement is particularly advantageous in cases when the temperature of the primary fluid exiting a cold exchange zone Z_{F6} , Z_{F7} is close to the temperature of the primary fluid that circulates between the consecutive concerned materials M_{111} , M_{113} and M_{112} , M_{114} . In fact, reinjecting in primary circuit P_{50} primary fluid that has the same temperature as the fluid that circulates in the primary circuit does not affect

the thermal gradient established in the primary circuit. This allows exploiting the thermal output of thermal generator 50 by means of cold exchange zones Z_{F6} , Z_{F7} without negative impact on its efficiency.

- 5 In addition, implanting more magnetocaloric elements in thermal generator 50 allows increasing its thermal output and/or its thermal gradient.

The magnetocaloric thermal generator 60 represented in figures 6A and 6B is an embodiment variant of thermal generator 40 of figures 4A and 4B and differs from it
 10 by the fact that it comprises only one bypass pipe D_9 with an exchange zone Z_{F8} , this pipe dividing into two portions after cold exchange zone Z_{F8} to reinject the primary fluid at injection points I_6 and I_7 . This reinjection is the same as that described in reference to figures 4A and 4B. It has the additional advantage of reducing the volume of thermal generator 60, as it requires fewer pipes for the circulation of the
 15 primary fluid.

The magnetocaloric thermal generator 70 represented in figures 7A, 7B and 9 is an embodiment variant of thermal generator 60 of previous figures 6A and 6B and differs from it by the fact that stages E_{10} and E_{20} comprise more magnetocaloric
 20 elements M_{111} , M_{112} , M_{113} , M_{114} , M_{221} , M_{222} , M_{223} , M_{224} , in order to increase the thermal output and/or the thermal gradient of the latter and therefore to increase its capacity to cool the secondary fluid of a secondary circuit by means of a cold exchange zone Z_{F9} . Primary circuit P_{70} comprises one single bypass pipe D_{10} with an exchange zone Z_{F9} , this pipe dividing into two portions after cold exchange zone Z_{F9}
 25 to reinject the primary fluid at injection points I_{10} and I_{11} between the two stages E_{10} , E_{20} . Figure 9 is a perspective view of this thermal generator 70 comprising three primary circuits, in the magnetization state represented in figure 7B. All components of the three primary circuits are not visible on this figure. This figure 9 identifies in particular the three cold heat exchange zones Z_{F9} , Z'_{F9} and Z''_{F9} of the three primary
 30 circuits of thermal generator 70, as well as a hot heat exchange zone Z'_{C5} of one of

said primary circuits. The thermal generator 70 comprises a magnetic arrangement with three magnetic rotors R_1 , R_2 , R_3 which, due to their rotation about the longitudinal axis of thermal generator 70, subject the magnetocaloric elements to a magnetic field variation. The magnetic rotors R_1 , R_2 , R_3 comprise each a frame on which permanent magnets 2 are mounted. The magnetocaloric elements are mounted in two fixed supports S_{UP1} , S_{UP2} . The primary fluid is displaced by actuators formed by pistons 3 actuated by a control cam C_{70} whose cam profile is realized, installed, machined or calked on rotor R_2 .

The magnetocaloric thermal generator 80 represented in figures 8A and 8B is an embodiment variant of thermal generator 50 of figures 5A and 5B and differs from it by the fact that it comprises only one bypass pipe D_{11} with an exchange zone Z_{F10} , this pipe dividing into two portions after cold exchange zone Z_{F10} to reinject the primary fluid at injection points I_8 and I_9 . This reinjection is the same as that described in reference to figures 5A and 5B. It has the additional advantage of reducing the volume of thermal generator 80, as it requires fewer pipes for the circulation of the primary fluid.

The magnetocaloric thermal generator 90 represented in figure 9 comprises two bypass pipes D_{12} and D_{13} that have a common bypass pipe portion D_{12}' . The thermal generator 90 comprises two stages E_1 and E_2 connected by primary fluid displacement means or actuators 3. A first stage E_1 is positioned on cold side F of thermal generator 90 and the other stage E_2 is positioned on hot side C.

The first bypass pipe D_{12} connects outlet point S_7 on cold end F of thermal generator 90 to injection point I_{12} located in primary circuit P_{90} , on the hot end of stage E_1 , between actuator 3 and the hot end of magnetocaloric element M_{11} . The second bypass pipe D_{13} connects outlet point S_7 on cold end F of thermal generator 90 to the other point of the primary circuit located on the hot side of first stage E_1 , located between an actuator 3 and the hot end of magnetocaloric element M_{12} . Bypass pipes

D_{12} and D_{13} comprise a common pipe portion D_{12}' , in which a cold exchange zone Z_{F11} intended for achieving the heat exchange between the primary fluid and a secondary fluid of secondary circuit 61 is integrated. Moreover, bypass pipes D_{12} and D_{13} comprise each a device that controls the direction of circulation of the primary fluid.

So, the common bypass pipe portion D_{12}' that comprises a heat exchanger able to perform a heat exchange with the secondary heat transfer fluid of secondary circuit 61 receives the primary fluid exiting the cold side of magnetocaloric elements M_{11} and M_{12} of stage E_1 located on cold side F when they are in a demagnetization phase. This way, the primary fluid always passes through this common bypass pipe portion D_{12}' when it has reached the coldest temperature of the cycle. From this results that the heat exchange in exchange zone Z_{F11} is optimized. Moreover, the primary fluid that has undergone a raise of its temperature due to the heat exchange with the secondary circuit to be cooled is then reinjected in the primary circuit, between thermal stages E_1 and E_2 , at a point I_{12} , I_{13} of the primary circuit where the temperature is not the lowest. The possibility to adjust the fluid flow rate that can circulate towards bypass pipes D_{12} and D_{13} in order to regulate the thermal power that can be exchanged between the primary circuit and the secondary circuit in exchange zone Z_{F11} is particularly advantageous. So, the higher the volume flow of the primary fluid passing through this exchange zone Z_{F11} will be, the more important the exchange will be. Advantageously, thanks to the positioning of exchange zone Z_{F11} in a bypass pipe, the raise of the temperature of the primary fluid due to the heat exchange in exchange zone Z_{F11} has very little, or even no impact on the operation of thermal generator 90, in particular on its ability to maintain a thermal gradient with a high efficiency. This is made possible by the reinjection of the primary fluid heated after a heat exchange in a zone of primary circuit P_{90} where the temperature of the primary fluid is not the lowest.

The thermal generator 90 represented in figures 10A and 10B is particularly advantageous for cooling or tempering in continuous operation a secondary fluid that circulates continuously in the secondary circuit through exchange zone Z_{F11} . In fact, the positioning of heat exchange zone Z_{F11} integrated serially in bypass pipes D_{12} , D_{13} in which the primary fluid circulates unidirectionally allows achieving a cross-flow exchange in heat exchange zone Z_{F11} , which favors the heat exchange.

The magnetocaloric thermal generator 100 represented in figures 11A and 11B presents the same advantages as those described in relation with thermal generator 90. It differs from it by the displacement of the primary fluid in a primary circuit P_{100} and by the magnetic cycles of magnetocaloric elements M_{11} , M_{12} , M_{21} and M_{22} . In fact, in the primary circuit P_{100} represented, the magnetocaloric elements are connected serially and a means for displacing the primary fluid or actuator 3 ensures the alternated displacement of the primary fluid in two opposite directions. The primary fluid passes through magnetocaloric elements M_{11} , M_{12} , M_{21} and M_{22} towards cold side F of thermal generator 100 when they are in a demagnetized state and it passes through magnetocaloric elements M_{11} , M_{12} , M_{21} and M_{22} towards hot side C when they are in a magnetized state. The injection points I_{12} and I_{13} of the bypass pipes are positioned between magnetocaloric elements M_{11} , M_{21} and M_{12} , M_{22} that are, in this variant, in a same magnetization state.

The magnetocaloric thermal generator 110 represented in figures 12A and 12B presents the same advantages as those described in relation with thermal generator 90. It differs from it by the positioning of injection points I_{14} and I_{15} of bypass pipes D_{14} and D_{15} . In fact, each injection point I_{14} and I_{15} is positioned between a magnetocaloric element M_{21} , M_{22} of hot stage E_2 and hot exchange zone Z_{C6} . Each injection point I_{14} and I_{15} thus allows injecting primary fluid whose temperature has been raised in cold exchange zone Z_{F11} in the primary circuit, at the outlet of a magnetocaloric element M_{21} or M_{22} , from which the primary fluid having undergone heating exits and flows towards hot exchange zone Z_{C6} . Here too, the impact of the

heat exchange on the temperature of the primary fluid is reduced, which allows achieving a heat exchange in cold exchange zone Z_{F11} without decreasing the efficiency of thermal generator 110.

5 Of course, the magnetocaloric thermal generator 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110 according to the invention can comprise several primary circuits. Moreover, these primary circuits can comprise a number of magnetocaloric elements different from what is represented in the attached figures.

10 Moreover, the shape of magnetocaloric elements M_{11} , M_{12} , M_{21} , M_{22} , M_{111} , M_{112} , M_{113} , M_{114} , M_{221} , M_{222} , M_{223} and M_{224} is not restricted to a rectangular part. Another shape can be considered. In addition, every magnetocaloric element can be made of several parts attached or fluidically connected in series to each other.

15 Possibilities for industrial application:

This description shows clearly that the invention allows reaching the goals defined, that is to say allow achieving an important heat exchange either on cold side F or on hot side C of magnetocaloric thermal generator 10, 20, 30, 40, 50, 60, 70, 80, 90,
20 100, 110 without disturbing the operation of the latter while optimizing its efficiency.

The thermal generator, as well as the method according to the invention, can find an application in all thermal areas, such as for example the area of heating, air conditioning, tempering, cooling or others, however without being restricted to these,
25 at competitive costs and with reduced space requirements.

The present invention is not restricted to the examples of embodiment described, but extends to any modification and variant which is obvious to a person skilled in the art while remaining within the scope of the protection defined in the attached claims.

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Claims

1. Magnetocaloric thermal generator (10, 20, 30, 40, 50, 60, 70, 80) comprising at least one primary circuit (P₁₀, P₂₀, P₃₀, P₄₀, P₅₀, P₆₀, P₇₀) fluidically connecting magnetocaloric elements (M₁₁, M₁₂, M₂₁, M₂₂, M₁₁₁, M₁₁₂, M₁₁₃, M₁₁₄, M₂₂₁, M₂₂₂, M₂₂₃, M₂₂₄) by means of a heat transfer fluid called primary fluid flowing alternately back and forth, said magnetocaloric elements (M₁₁, M₁₂, M₂₁, M₂₂, M₁₁₁, M₁₁₂, M₁₁₃, M₁₁₄, M₂₂₁, M₂₂₂, M₂₂₃, M₂₂₄) being subjected to the variable magnetic field of a magnetic system (2) that creates alternately in each magnetocaloric element (M₁₁, M₁₂, M₂₁, M₂₂, M₁₁₁, M₁₁₂, M₁₁₃, M₁₁₄, M₂₂₁, M₂₂₂, M₂₂₃, M₂₂₄) a magnetic heating phase and a magnetic cooling phase, generator wherein the primary system comprises a cold side (F) and a hot side (C) at which magnetocaloric elements (M₁₁, M₁₂; M₁₁₁, M₁₁₂ et M₂₁, M₂₂, M₂₂₃, M₂₂₄) are fluidically connected with each other, thermal generator characterized in that at least one of said hot (C) and cold (F) sides of the primary circuit comprises at least one outlet point (S₁, S₂, S₃, S₄, S₅, S₆) connected to another point of the primary circuit called injection point (I₁, I₂, I₃, I₄, I₅, I₆, I₇, I₈, I₉, I₁₀, I₁₁) by means of at least one bypass pipe (D₁, D₂, D₃, D₄, D₅, D₆, D₇, D₈, D₉, D₁₀, D₁₁) allowing the primary fluid to be displaced only from the outlet point (S₁, S₂, S₃, S₄, S₅, S₆) towards the injection point (I₁, I₂, I₃, I₄, I₅, I₆, I₇, I₈, I₉, I₁₀, I₁₁).
2. Thermal generator according to claim 1, characterized in that the magnetocaloric elements (M₁₁, M₁₂, M₂₁, M₂₂, M₁₁₁, M₁₁₂, M₁₁₃, M₁₁₄, M₂₂₁, M₂₂₂, M₂₂₃, M₂₂₄) are distributed in at least two stages (E₁, E₂, E₁₀, E₂₀), and in that the magnetocaloric elements (M₁₁, M₁₂; M₁₁₁, M₁₁₂) of one of said stages (E₁, E₁₀) are connected fluidically with each other on the cold side (F) and the magnetocaloric elements (M₂₁, M₂₂, M₂₂₃, M₂₂₄) of another of said stages (E₂, E₂₀) are connected fluidically with each other on the hot side (C).

3. Thermal generator according to any of the previous claims, characterized in that the bypass pipe ($D_1, D_2, D_3, D_4, D_5, D_6, D_7, D_8, D_9, D_{10}, D_{11}$) is thermally connected to a secondary circuit (6) by at least one heat exchange zone ($Z_{F1}, Z_{F2}, Z_{F3}, Z_{F4}, Z_{F5}, Z_{F6}, Z_{F7}, Z_{F8}, Z_{F9}, Z_{F10}, Z_{F11}$).

5

4. Thermal generator according to claim 3, characterized in that the heat exchange zone ($Z_{F1}, Z_{F2}, Z_{F3}, Z_{F4}, Z_{F5}, Z_{F6}, Z_{F7}, Z_{F8}, Z_{F9}, Z_{F10}, Z_{F11}$) is designed to achieve a counter-current displacement between the primary fluid and a secondary fluid of said secondary circuit (6).

10

5. Thermal generator according to claim 3, characterized in that the heat exchange zone ($Z_{F1}, Z_{F2}, Z_{F3}, Z_{F4}, Z_{F5}, Z_{F6}, Z_{F7}, Z_{F8}, Z_{F9}, Z_{F10}$) is designed to achieve a co-current displacement between the primary fluid and a secondary fluid of said secondary circuit (6).

15

6. Thermal generator according to claim 3, characterized in that the heat exchange zone ($Z_{F1}, Z_{F2}, Z_{F3}, Z_{F4}, Z_{F5}, Z_{F6}, Z_{F7}, Z_{F8}, Z_{F9}, Z_{F10}$) is designed to achieve a cross-current displacement between the primary fluid and a secondary fluid of said secondary circuit (6).

20

7. Thermal generator according to any of the previous claims, characterized in that the bypass pipe ($D_1, D_2, D_3, D_4, D_5, D_6, D_7, D_8, D_9, D_{10}, D_{11}$) comprises a device (5) for adjusting the flow rate of the primary fluid that circulates in it.

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8. Thermal generator according to any of the previous claims, characterized in that said at least one outlet point ($S_1, S_2, S_3, S_4, S_5, S_6$) is located in the cold side (F) of the primary circuit.

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9. Thermal generator according to any of claims 1 to 7, characterized in that said at least one outlet point is located in the hot side (C) of the primary circuit.

10. Thermal generator according to claim 8, characterized in that the injection point (I₁, I₂, I₃, I₄, I₅) is located in the hot side (C) of the primary circuit.

5 11. Thermal generator according to claim 9, characterized in that the injection point is located in the cold side (F) of the primary circuit.

12. Thermal generator according to any of claims 1 to 9, characterized in that the injection point (I₆, I₇, I₁₀, I₁₁, I₁₂, I₁₃) is located between two stages (E₁, E₂ ; E₁₀, E₂₀)
 10 of magnetocaloric elements (M₁₁, M₁₂, M₂₁, M₂₂, M₁₁₁, M₁₁₂, M₁₁₃, M₁₁₄, M₂₂₁, M₂₂₂, M₂₂₃, M₂₂₄).

13. Thermal generator according to any of claims 1 to 9, characterized in that the injection point (I₈, I₉) is located between consecutive magnetocaloric elements (M₁₁₁,
 15 M₁₁₂, M₁₁₃, M₁₁₄, M₂₂₁, M₂₂₂, M₂₂₃, M₂₂₄) of each stage (E₁₀, E₂₀).

14. Method for cooling a fluid called secondary fluid by a magnetocaloric thermal generator according to any of the previous claims, characterized in that it consists in connecting thermally the secondary circuit (6) in which the secondary fluid circulates
 20 by means of at least one heat exchange zone (Z_{F1}, Z_{F2}, Z_{F3}, Z_{F4}, Z_{F5}, Z_{F6}, Z_{F7}, Z_{F8}, Z_{F9}, Z_{F10}, Z_{F11}) to a bypass pipe (D₁, D₂, D₃, D₄, D₅, D₆, D₇, D₈, D₉, D₁₀, D₁₁) of said magnetocaloric thermal generator and to have said secondary fluid circulating continuously in said secondary circuit.