March 18, 1952 C. CHILOWSKY 2,589,775

METHOD AND APPARATUS FOR REFRIGERATION

Filed Oct. 12, 1948

2 SHEETS--SHEET 1

FIG. 1.

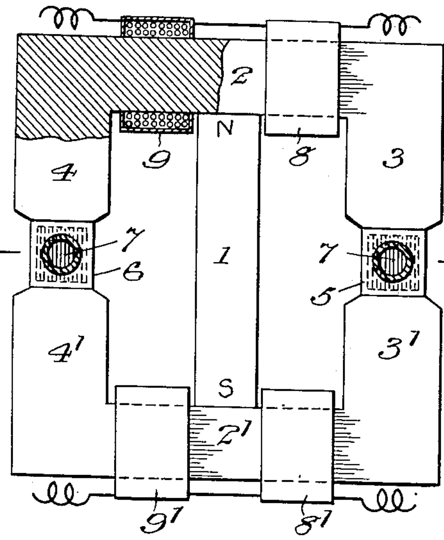

FIG. 2.

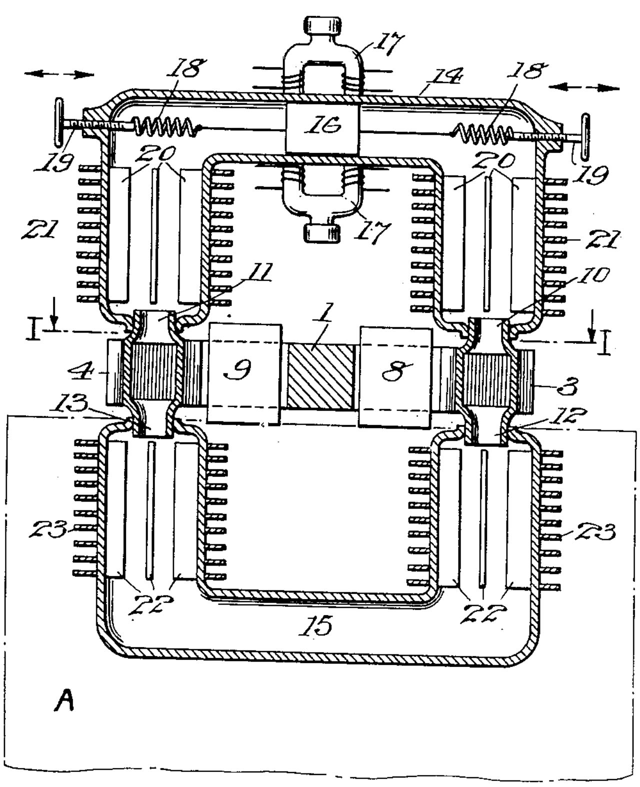

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FIG. 3.

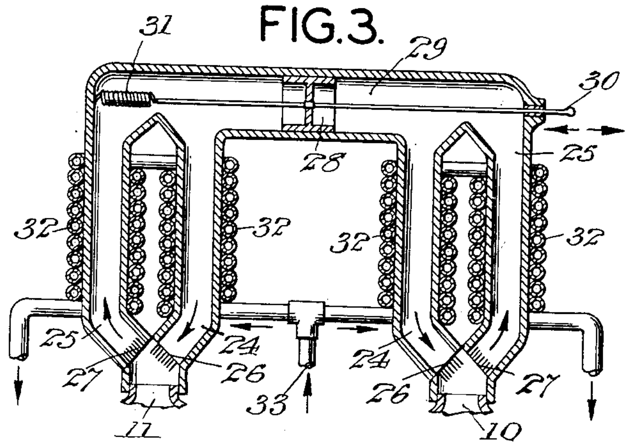


FIG. 5.

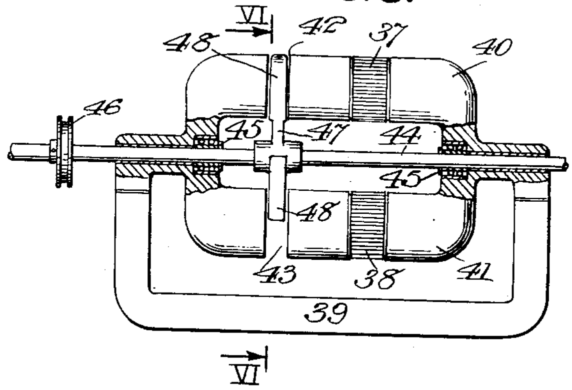
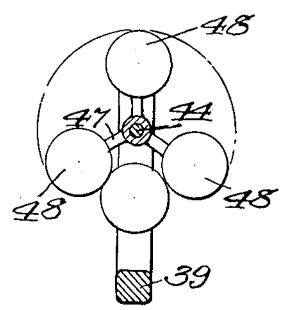


FIG. 6.



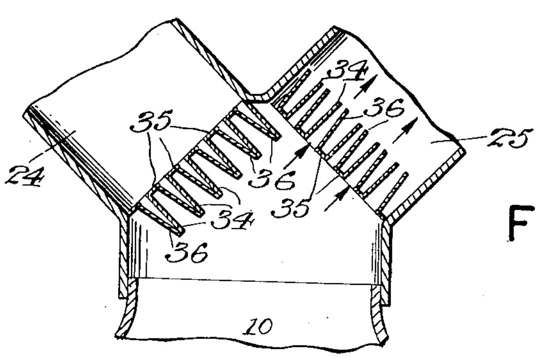


FIG. 4.

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METHOD AND APPARATUS FOR REFRIGERATION

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Application October 12, 1948, Serial No. 54,041

20 Claims. (Cl. 62—1)

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This invention relates to a method and apparatus for refrigeration, and has for an object the provision of thermo-magnetic means adapted to cause refrigeration by the application of an alternating electric current as specified.

In the applicant's copending applications Ser. No. 627,832, filed November 10, 1945, and Ser. No. 635,988, filed December 19, 1945, (Patents No. 2,510,800 and No. 2,510,801, June 6, 1950), were disclosed methods and means for generating alternating electric current by arranging in the generator armature a ferromagnetic section of "composite laminations" with Curie point temperature progressively varying from one end to the other, this section being alternately heated by contact with a fluid maintained at a temperature slightly higher than the highest Curie point, and cooled by contact with a fluid maintained at a temperature lower than the lowest Curie point. The term "composite lamination," as used herein and in Patent No. 2,510,801, includes not only a lamination made up of distinct zones with progressively varying Curie point temperatures, but also any agglomeration or configuration of ferromagnetic elements having, in the direction of movement of the fluid or fluids, a progressive graduation of Curie point temperature and capable of passing a magnetic flux. An assembly of such composite laminations occupying a gap in an armature is termed a "composite section."

The Curie interval is the temperature interval along which the permeability of the ferromagnetic material drops abruptly, or more or less abruptly, depending generally on the strength of the magnetic field.

If a greater output is required the periodical variation of the temperature may exceed the Curie interval proper of the corresponding element or corresponding composite section.

In said copending applications, and particularly Ser. No. 635,988 (Patent No. 2,510,801), the fluid or fluids (preferably liquid alkaline metals) are moved so as to alternately heat and cool each part of the composite section in the neighborhood of the Curie point temperatures of said parts, thus producing variations of the magnetic flux in the armature branches and inducing an alternating electric current in the armature windings. A portion of the heat supplied to the heating fluid is transformed into electric energy, the efficiency of this operation when composite laminations are used (Patent No. 2,510,801) being increased over that obtained from a single Curie point section (Patent No. 2,510,800) in approximately the same ratio as that between the total

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range of temperature in the first case and the small range of the Curie interval in the second case.

Referring particularly to the use of a single fluid which is reciprocated past the composite laminations, the arrangement is such that the temperature of the fluid column varies progressively in the same direction as the Curie point temperatures of the parts of the laminations, so that each said part is heated and cooled by fluid at a temperature only slightly higher or lower than the limits of the Curie interval of said part, or even within said limits. Thus the whole composite lamination is simultaneously heated (or cooled) along its total Curie interval, by varying the temperature of each part of the lamination through a range corresponding approximately to the Curie interval of said part.

It is an object of the present invention to utilize a similar system of composite laminations heated and cooled in the same manner, in order to obtain a refrigerating effect from an electric current, instead of producing an electric current from heat.

According to the present invention a system of composite laminations, in heat-exchange relation with fluids (preferably metallic), is arranged so that the laminations may be heated and cooled internally, in the neighborhood of the graduated Curie point temperature of the several parts thereof, by magnetization or demagnetization of the laminations. This is in accordance with the known fact that magnetization of a ferromagnetic material, maintained at a temperature approaching its Curie point, produces an intense interior heating of the material whereas demagnetization produces an intense cooling.

In this system the circulation of the so-called "heating" and "cooling" fluids or fluid is used to draw from the laminations the high temperature heat produced by magnetization, and to supply to the laminations the low temperature heat which they lose through demagnetization. This transfer of low temperature heat from the fluid to the laminations results in the refrigeration of parts of the system in heat-exchange relation with the fluid from which the heat is withdrawn.

In order to effect such an operation a "composite section" as previously described is placed in a gap of a magnetic armature, maintained at temperatures approximating the Curie points of the parts of the section and subjected simultaneously to the action of a variable-intensity magnetic field and to the alternating circulation of a suitable fluid. This alternating circulation is arranged to act in phase with the alternate magnetization and demagnetization of the section. Consequently the fluid issuing from the passages provided in the composite section during the magnetization stage and accumulated in a "hot chamber" will be warmer, while the fluid issuing in the opposite direction from the passages during the demagnetization stage and accumulated in a "cold chamber" will be cooler. Heat may be removed from the hot chamber by the circulation of ambient air or otherwise, and heat is supplied to the cold chamber by transfer from the parts of the system which are to be refrigerated.

The temperatures of the fluid in the respective chambers are controlled, preferably automatically, for instance by regulating the rates of heat dispersion from (and possibly of heat absorption by) the fluid in said chambers, respectively, so that said fluid is at a temperature which maintains the composite section at optimal temperatures in the neighborhood of the Curie interval. Such control may also be effected by automatic regulation of the intensity of magnetization and demagnetization, as a function of the deviation of the temperatures from their desired ranges, by means of a thermocouple adjacent the "cold" side of the section controlling the intensity of the alternating current and a thermocouple adjacent the "hot" side controlling the rate of heat dispersion.

This refrigeration system can be adapted for operation with a wide variety of circulating fluids. Metallic liquids have the advantage of high specific heat, while a suitable Na-K alloy can go down to −12° C. and Hg can go almost to −30° C. Gases, particularly under pressure, may also be used, such gases including air, rare gases, helium, nitrogen, carbon dioxide, etc.; and non-metallic liquids having a sufficiently low freezing point are also suitable. In some cases a gas may be circulated and itself become liquefied, or a liquid may be cooled frozen in the course of the refrigeration procedure, by continuously supplying the gas or liquid to the hot chamber and removing them from the cold chamber.

As an example of ferromagnetic materials having low Curie point temperatures, alloys of Ni and Si, in various ratios, are available and other metals or alloys having the characteristics desired can readily be found. A Ni-Si alloy with 6% Si has a Curie temperature of −45° C. and Ni-Mo alloys also have Curie points in the low temperature range. The total Curie interval of the composite laminations should preferably include temperatures in the vicinity of the ambient temperature at the place of use of the system in order to facilitate starting of the operation; but even if started at temperatures of low efficiency the system will more or less promptly become stabilized at normal operating temperatures.

Practical embodiments of the invention are shown in the accompanying drawings in which:

Fig. 1 represents a horizontal section through the apparatus on the line I—I of Fig. 2, parts of the magnet and a winding being broken away and shown in section;

Fig. 2 represents a vertical section through the magnet, hot and cold fluid chambers and composite sections, taken on the line II—II of Fig. 1;

Fig. 3 represents a vertical section through a modified form of hot chamber, corresponding to the upper part of Fig. 2;

Fig. 4 represents a detail vertical section showing on a larger scale the check valves of Fig. 3;

Fig. 5 represents diagrammatically, in elevation, a modified arrangement of the magnet, armature, and flux-controlling means, and

Fig. 6 represents a section on the line VI—VI of Fig. 5.

Referring to the drawings, and particularly Figs. 1 and 2, a permanent magnet **1** is shown as having on its ends branched armatures **2**, **2'**, the magnetic flux being divided between the right branches **3**, **3'** and the left branches **4**, **4'**. The gaps between the ends of the respective branches are occupied by chambers **5**, **6**, in which the composite laminations **7** are mounted. The laminations lie vertically, extending from side to side of the chambers **5**, **6** in the direction of the magnetic flux, and are spaced apart to leave vertical channels for the circulation of the fluid preferably in contact with both surfaces of each lamination. The branches **3**, **3'** and **4**, **4'** are provided with windings **8**, **8'** and **9**, **9'** respectively, through which is passed an alternating magnetization current; the current through the windings **8** and **8'** being dephased by 180° with respect to the current through the windings **9** and **9'**, as by suitable selection of the direction of winding.

Under the superposed action of the alternating current and the bifurcated magnetomotive force of the permanent magnet the resulting magnetic flux is subjected, in each branch of the armature, to a variation from zero to a maximum. The intensity of the magnetization current in the coils being generally chosen sufficiently high to compensate alternately (partly or totally) the bifurcated magnetic field (or magnetomotive force) of the permanent magnet in the branches. Consequently the magnetic flux resulting from this superposition flows alternately through the right and left branches varying in each branch, in intensity only, from zero to a maximum and not changing in sign or direction. Consequently, the composite laminations **7** in the chambers **5** and **6** are subjected, in the two branches, to an internal heating and cooling produced by the magnetization and the demagnetization by the magnetic fluxes. The heatings and coolings in the right branch are phase-displaced, in relation to those in the left part, by 180°.

The chambers **5**, **6** have circular upper openings **10**, **11** and lower openings **12**, **13**, the upper openings communicating with the ends of an inverted U-shaped hot chamber **14** and the lower openings communicating with the ends of a U-shaped cold chamber **15**. The right and left parts of the chamber **14** are connected by the horizontal middle part in which may be placed a sliding piston **16** adapted to be oscillated by the electromagnetic coupling **17**; the oscillations of the piston being stabilized by its connection to the springs **18** on adjusting screws **19**. Dispersion of heat from the fluid in the hot chamber **14** is facilitated by the provision of internal vertical fins **20** and external annular fins **21**. The cold chamber **15** is also preferably provided with internal vertical fins **22** and external annular fins **23**, to improve the absorption of heat by the fluid in the chamber from the space to be refrigerated (indicated by the enclosure A). If desired, the piston **16** and associated parts may be located in the cold chamber, or the hot and cold chambers may be reversed.

The openings **10**, **11**, **12**, **13** are shown as forming nozzles, out of which the fluid passes to the respective chambers **14**, **15** with considerable turbulence and radial circulation, thereby further improving the exchange of heat between the fluid and the walls of the chambers.

In operation, the chambers 5, 6, 14 and 15 are filled with a suitable fluid of the character hereinabove described; the electromagnetic coupling 17 is operated to oscillate the piston 16; the windings 8, 8' and 9, 9' are supplied with alternating current, dephased as described, and of a frequency corresponding to the oscillation of the piston; and the fluid column is thus caused to oscillate vertically past the composite laminations in the chambers 5 and 6. For most efficient operation, the laminations should be at temperatures in the vicinity of their Curie points. When the magnetic flux induced by the coils in the armature branches on one side is in the same direction as the permanent magnetism, the laminations on that side will be strongly magnetized by the addition of the two magnetizations and will become heated, the heat being removed by the fluid passing from the cold chamber to the hot chamber in heat-exchange relation to the laminations. At the same time the magnetic flux on the second side is in opposition to the permanent magnetism, so that the laminations on that side are demagnetized and cooled to a point where they take up heat from the fluid which passes them in the direction from the hot chamber to the cold chamber. The actions just described take place alternately on both sides, and there is thus a continuous absorption of heat from the space A into the cold chamber and conveyance of this heat out to the hot chamber from which it is continuously dissipated.

In order to effect the oscillation of the column with a maximum amplitude and a minimum of electric energy, the force of the springs 18 may be chosen in such a manner that the mechanical oscillating system, constituted by the liquid column, the piston 16 and the springs 18 (symbolizing the elastic forces of the oscillating system), has a natural frequency of oscillation equal to the frequency of the electric current.

In Fig. 3 is shown a modification of the hot chamber in which the fluid in each side is forced to circulate through pipes which are enclosed in cooling coils, providing a more intense cooling than is normally possible with the fin structure of Fig. 2. In the modified form, each side of the hot chamber, above the openings 10 and 11, is divided into pipes 24 and 25 having at their bottom ends check valves or the like 26, 27 (shown diagrammatically in Fig. 3 and in detail in Fig. 4). The valves 26 in pipes 24 permit only a downward flow and the valves 27 in pipes 25 permit only an upward flow. A piston 28 is fitted into the upper horizontal part 29 of the hot chamber, and is oscillated by mechanical means (e. g., a motor and crank or cam, not shown) connected to the pull rod 30, the opposite side of the piston being connected to a tension spring 31, if necessary. It will be understood that this piston operating means is, in general, interchangeable with the arrangement shown in Fig. 2.

Each of the pipes 24, 25 is surrounded by a cooling coil 32 through which a cooling fluid is circulated from a common supply pipe 33; a desirable arrangement being that shown in which the cooling fluid on each side flows first around the pipe 24 and then around the pipe 25.

Details of the check valves 26, 27 are shown in Fig. 4, in which the fixed lips 34 are mounted on supports 35 extending across the lower ends of the pipes 24, 25. Associated with each lip 34 and normally resting against it is a hinged or flexible flap 36, the lips and flaps in pipe 24 being directed downward and those in pipe 25 being directed upward.

In the operation of the modified hot chamber shown in Figs. 3 and 4, the oscillation of the piston in either direction causes the fluid to flow upward in the pipe 25 on one side and downward in the pipe 24 on the opposite side; the fluid on each side being thus caused to circulate up through valve 27 and pipe 25, across the top to the adjoining pipe 24, and downward through pipe 24 and valve 26. The fluid enters valve 27 at its highest temperature directly from the chamber 5 or 6, is cooled during its progress through pipes 24 and 25 (in reverse order with respect to the fluid in cooling coils 32), and returns through valve 26 to the chamber 5 or 6 at a substantially lower temperature. The cycling of magnetic effects and resulting refrigerating action is the same as in the case of Figs. 1 and 2.

The magnetization and demagnetization of the composite laminations by alternating electromagnetic means as described above is particularly applicable to refrigeration installations of limited size and has the advantage of requiring no motors, compressors, or the like. In some cases, however, it may be convenient to provide mechanical means for varying periodically, at the required frequency, the magnetic flux through the armature in which is located the section of composite laminations. Such mechanical means is shown, more or less diagrammatically, in Figs. 5 and 6.

Referring to Figs. 5 and 6, the composite laminations 37, 38 correspond to the laminations 7 in chambers 5 and 6, and are assumed to be located in a fluid circulation system of the type described above. A permanent magnet 39 is connected at its ends to an armature having two branches 40, 41, in which the sections of laminations 37, 38 are located, and the branches are cut completely by gaps 42, 43. An axle 44, supported on bearings 45 and arranged to be motor driven by pulley 46, is located midway between the gaps 42, 43, and a three-armed spider 47 is mounted on the axle for rotation therewith. Each arm of the spider carries at its end a flat disk 48 of soft iron, laminated if desired, and of a size to substantially fill the gaps in the armature without coming in contact with the sides of said gaps. When the spider is rotated, the disks 48 will alternately fill the gap in one branch of the armature, permitting the magnetic flux to pass and magnetize the corresponding laminations 37 or 38, while the gap in the opposite branch is open, and then open the first gap while filling the opposite one. The speed of rotation of the spider determines the frequency of magnetization and demagnetization of the respective laminations 37, 38, this frequency being synchronized as required with the oscillation of the heating and coiling fluid.

In the embodiments of the invention described and shown, it is stated and assumed that the laminations 7, 37 and 38 are of the composite type, each having parallel zones with Curie points progressively varying in the direction of flow of the heating and cooling fluid. The efficiency of this arrangement is substantially greater than in the case of homogeneous laminations having a single Curie point, but the latter is naturally included within the scope of the invention and may, because of its simplicity, be found useful under certain circumstances.

The composite sections shown herein are described as including composite laminations spaced apart and lying in the direction of flow of the fluid. An alternative and equivalent arrangement is shown in Patent No. 2,510,801 wherein a series of laminations each having a single Curie point are stacked in face-to-face relation (separated by insulating layers, if desired) in their order of progressively varying Curie points, the assembly being provided with perforations to permit passage of the fluid in contact with each of the laminations in the proper order. Alternative means for oscillating the fluid column are also shown in said patent and in Patent No. 2,510,800, and include maintaining the oscillation by the properly timed evaporation of a low boiling point liquid or obtaining an equivalent result by means of valves arranged to pass alternately a hot or cold fluid.

The temperature in the space containing the material to be refrigerated can be regulated at will, notwithstanding the desirable strict maintenance of the cold end of the section near the lowest Curie temperature, as by the controlled circulation of an intermediate cooling fluid (cold brine or the like) to the point where the desired refrigeration is to occur. The control (automatic or not) of the circulation of the brine permits maintaining the final refrigerated space at the temperature desired, the functioning of the thermo-magnetic refrigerator automatically stabilizing itself, as described, according to the amount of heat to be removed from the brine. The temperature in the space A can very simply be regulated by the provision of adjustable insulation on the cold chamber, to control the rate of heat absorption thereby.

The automatic maintenance of both extreme Curie temperatures at the two ends of the composite section, can also be obtained by using for the control of the operating electric current, and of the heat abduction from the hot liquid, the rectified differential current produced by two separate symmetrical windings placed on two separate parts (hot and cold) of the same armature branch adjacent to the composite section, as suggested and explained in connection with Fig. 8 of Patent No. 2,510.801.

It will be understood that various changes may be made in the construction, form and arrangement of the several parts and in the steps of the method without departing from the spirit and scope of the invention, and hence I do not intend to be limited to the details herein shown and described except as they may be required to be included in the claims.

What I claim is:

1. The method of refrigeration in an apparatus containing ferromagnetic sections having Curie point temperatures approximating the desired temperature of refrigeration located in gaps in a closed ferromagnetic armature, which comprises, causing a magnetic flux to traverse the armature, subjecting the ferromagnetic sections alternately to magnetization and demagnetization, passing a fluid in heat-exchange relation with said sections alternately in opposite directions, such passage of fluid being so timed that the phase of magnetization of each section coincides with the passage of fluid in one direction and the phase of demagnetization coincides with passage in the opposite direction, removing heat from the fluid after passing a section in the former direction, and supplying heat to the fluid after passing a section in the latter direction, whereby the space from which heat is supplied is refrigerated.

2. The method of refrigeration according to claim 1 in which each ferromagnetic section is so constituted as to have progressively varying Curie point temperatures, and in which the fluid passes said sections in directions corresponding to the variation of Curie point temperatures therein.

3. The method of refrigeration according to claim 2 in which the temperature of the fluid as it passes said sections is maintained approximately in the region of the Curie intervals of adjacent parts of the sections.

4. The method of refrigeration according to claim 1 in which the armature is provided with coils, in which an alternating electric current is passed through said windings in order to effect the magnetization and demagnetization of the sections, and in which the alternation in direction of flow of the fluid is in phase with said current.

5. The method of refrigeration according to claim 2 in which the armature is provided with coils, in which an alternating electric current is passed through said windings in order to effect the magnetization and demagnetization of the sections, and in which the alternation in direction of flow of the fluid is in phase with said current.

6. The method of refrigeration according to claim 1 in which the armature is provided with open gaps, in which said gaps are alternately closed and opened in order to effect the magnetization and demagnetization of the sections by establishing and cutting the magnetic flux, and in which the alternation in direction of flow of fluid is in phase with said closing and opening of the gaps.

7. The method of refrigeration according to claim 2 in which the armature is provided with open gaps, in which said gaps are alternately closed and opened in order to effect the magnetization and demagnetization of the sections by establishing and cutting the magnetic flux, and in which the alternation in direction of flow of the fluid is in phase with said closing and opening of the gaps.

8. Refrigeration apparatus of the character described comprising, a permanent magnet, an armature arranged to concentrate the magnetic flux between the ends of said magnet, a ferromagnetic section occupying a gap in said armature, the section having channels to permit the passage of a fluid in heat-exchange relation therewith and including a part having a Curie point temperature approximating the desired temperature of refrigeration, means for alternately magnetizing and demagnetizing the section, means for passing a fluid in heat-exchange relation with the section in one direction during the magnetization phase and in the opposite direction during the demagnetization phase, means for removing heat from the fluid after its passage in the first direction and means for supplying heat to the fluid after its passage in the opposite direction.

9. Apparatus according to claim 8 in which the ferromagnetic section is so constituted as to have a plurality of Curie point temperatures progressively varying in directions corresponding to the direction of the passage of fluid in heat-exchange relation therewith.

10. Apparatus according to claim 8 in which

the magnetizing and demagnetizing means includes windings on the armature and alternating electric current supplied to said windings.

11. Apparatus according to claim 8 in which the magnetizing and demagnetizing means includes a gap in the armature and mechanical means for closing and opening said gap, whereby the magnetic flux across said gap is alternately established and cut.

12. Refrigeration apparatus of the character described comprising, a permanent magnet, a bifurcated armature arranged to concentrate in its two branches the magnetic flux between the ends of the magnet, ferromagnetic sections occupying gaps in said branches, the sections having channels to permit the passage of a fluid in heat-exchange relation therewith and having a Curie point temperature approximating the desired temperature of refrigeration, means for alternately magnetizing and demagnetizing the sections, means for passing a fluid in heat-exchange relation with the sections in one direction during the magnetization phase and in the opposite direction during the demagnetization phase, means for removing heat from the fluid after its passage in the first direction and means for supplying heat to the fluid after its passage in the opposite direction.

13. Apparatus according to claim 12 in which each section is so constituted as to have a plurality of Curie point temperatures progressively varying in directions corresponding to the direction of the passage of fluid in heat-exchange relation therewith.

14. Apparatus according to claim 12 in which the magnetization and demagnetization means includes windings on the armature branches and alternating electric current supplied to said windings.

15. Apparatus according to claim 12 in which the magnetization and demagnetization means includes a gap in each armature branch and mechanical means for closing and opening said gaps.

16. In a refrigeration apparatus of the character described, a closed fluid circulation system comprising, an elongated cold chamber, chambers containing ferromagnetic laminations and provided with fluid passages between said laminations in communication with each end of said cold chamber, an elongated hot chamber communicating at each end with said second named chambers, means for oscillating a fluid column through said chambers, means for facilitating the absorption of heat by fluid in the cold chamber, and means for facilitating the removal of heat from the fluid in the hot chamber.

17. An apparatus according to claim 16 in which the fluid oscillating means comprises a sliding piston.

18. An apparatus according to claim 16 in which the volumes of the hot chamber and of the cold chamber are each substantially greater than the volumes of the second named chambers.

19. An apparatus according to claim 16 in which the volumes of the hot chamber and of the cold chamber are each substantially greater than the volumes of the second named chambers, and in which the openings from the second named chambers into the hot and cold chambers are in the form of nozzles adapted to project the fluid into said hot and cold chambers with appreciable turbulence.

20. An apparatus according to claim 16 in which the hot chamber is divided adjacent its ends into two pipes and which includes a check valve opening upwardly in one of each pair of pipes, a check valve opening downwardly in the other of each pair of pipes, and cooling means associated with said pipes.

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No references cited.