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Study And Analysis Of A Magnetic Heat Engine

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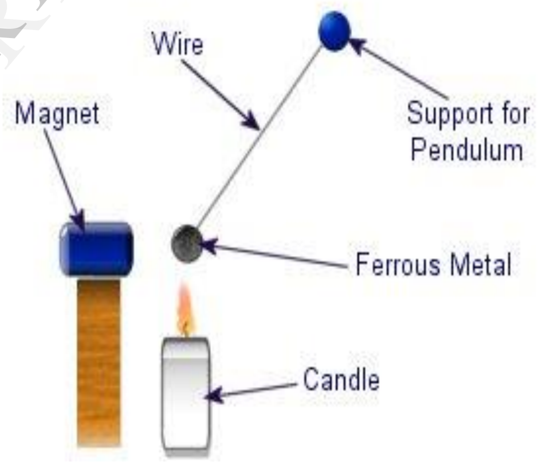
Abstract

Converting thermal energy into power had a long period of time in human history. Especially converting thermal energy to electric power is the most common energy source today. However, the efficiency of conversion is still very low. For e.g. the efficiency is about 40% for steam power plant and 30% for internal combustion engine. Almost 60-70% of energy is wasted. A magnetic heat engine directly converts heat to electricity, using emf induced by demagnetization. Generated power manifests as negative resistance, and almost any kind and shape of medium can be used. Electromagnetic engines are also tolerant to non-uniform heating, inherently non-contact and non-mechanical, easy to model and design, and operable at high frequencies. The engines are also suitable for augmented local heating, refrigeration without fluid refrigerants, efficient cooling of cryogenic components, and synchronous cooling of digital circuits, solid state power generation and improvement of power plant generation.

Keywords – *Cryogenic, Demagnetization, Electromagnetic, Refrigerants, Synchronous.*

1. INTRODUCTION

1.1 Brief description



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The Curie point is the temperature at which a material changes from a ferromagnetic to a paramagnetic state; this temperature is significant because a material will exhibit its greatest magneto caloric effect near the Curie temperature. The curie effect usually refers to a magnetic phenomenon discovered by Pierre Curie. She discovered that ferromagnetic substances exhibited a critical temperature transition, above which the substances lost their ferromagnetic behavior. This is now known as the Curie point (T_c)

A simple experiment, often named 'the curie effect' is a great way to practically demonstrate this important scientific principle.

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A ferrous metal object such as a screw is suspended by a length of stiff wire so that it can swing freely from left to right.

To one side of the pendulums swing, a magnet is fixed into a position where it attracts the mass on the pendulum, and holds it up preventing it from swinging. The magnet must be far enough away so that it holds the mass up, but without actually touching it.

When a heat source such as a candle is place under the ferrous mass, the temperature of the material will increase until it reaches the Curie point. When this occurs the thermal noise in the material prevents it from being held by the magnet and it will swing away. This will quickly allow the mass to cool and on its return swing (or before) the magnet will pull the mass back over the heat source, causing the whole process to start again.

Magneto caloric effect (MCE) has been discovered for over 100 years. Emil Gabriel Warburg discovered the magneto caloric effect in the iron in 1881. Soon after Warburg's discovery, Edison and Tesla tried to convert power from the magneto caloric effect of sift iron by heating and cooling. For a very long period of time, such technology was only applied in very low temperature refrigerators to cool down sample to few Kelvin to tens Kelvin since 1930's. For near room temperature magnetic refrigerator was not able to achieve until 1976. Gadolinium (Gd) has been used as a magnetic working material and demonstrated the magnetic refrigeration at near room temperature in 1976. Gd, which has a curie point of 293 Kelvin, is used as a working material by G. V. brown of National Aeronautics and Space Administration.

1.2 Brief summary

This invention done by Venkata Guruprasad generally relates to magnetic heat engines. More particularly, it is concerned with an electromagnetic heat engine for directly converting power between heat and electrical forms using magnetism.

Most of the electric power comes from using steam turbo-generates or hydroelectric power station or from gas turbines. These methods, while reducing the moving parts still involve an intermediate mechanical form as kinetic energy in a moving fluid medium and the flow of fluid is difficult to model and control. But in the magnetic heat engine the energy transfer is not confined by the surface of the medium and which converts heat to electricity directly without involving any intermediate mechanical form whatsoever. Hitherto only mechanical means have been used for the work transfers in magnetic engines, though they have been known for a century since Nikola Tesla's THERMOMAGNETIC MOTOR. Accordingly, it is an object of the present invention to provide a thermodynamic means for directly converting power between heat and electrical forms using magnetism. Another application of the invention is to provide a means for operating magnetic heat engines at higher speeds to obtain greater conversion of power densities, also to establish negative resistance as a useful model of power generation with the added feature that the power can be regulated and controlled by a low power input needed to setup the load current. A still further object of the invention is to provide a direct thermo dynamic means for cooling synchronous digital systems. The present invention consists of three parts:

An electromagnetic heat engine, inductively converting power between heat in a magnetic medium and current in an electric circuit magnetic Carnot cycle consists of magnetizing a magnetic medium at one temperature and demagnetizing the medium at a different temperature. If the susceptibility of the medium drops with rising temperature, as is commonly the case, heat gets absorbed during demagnetization and released during magnetization. Appropriate heat transfers are therefore required to keep the temperature steady during each of these isothermal operations. The temperature changes are effected by adiabatic magnetization or demagnetization operations. Work is done on the medium during magnetization and the medium does work as it demagnetizes but the work transfer are unequal because the susceptibility changes with the temperature. Performing magnetization cycles in synchronization with temperature cycles thus results in net conversion between heat and coherent power.

In the electromagnetic heat engine, the electric current does work in magnetizing the medium and conversely, the medium does work on the electrical circuit by the induced emf during demagnetization. The engine thus converts between heat and electrical power. Since the induced emf is proportional to the current, the work done by the medium instantaneously appears as a negative resistance in the circuit. The induced resistance also varies with the susceptibility, which depends on the instantaneous temperature; hence a net negative resistance is induced when operating as an engine.

2. DESCRIPTION OF THE PROCESS

When a magnetic field is applied to the MCEM and the MCEM is magnetized, the magnetic entropy, $S_{m,}$ is changed according to the magnetic field changed by the magnetic order of the material. Under the adiabatic condition, the magnetic entropy change, $\Delta S_{m,}$ must be compensated by an opposite change of the entropy associated with the lattice. The result is a change in temperature of the MCEM. In other words, when a magnetic field is applied to MCEM and loss its magnetic entropy, the temperature of the magnetic field rises up to compensate the magnetic entropy loss. When the magnetic field is removed away from the MCEM and increases its magnetic entropy, the temperature of the MCEM cool down to compensate the magnetic entropy loss.

By using MCEM together with proper thermodynamic cycles, some heat engine for cooling, or heating, can be designed.

There are four basic processes for MCE magnetic heat engine:

(A) Adiabatic magnetization: a MCEM is subjected to magnetic field in adiabatic condition, and the temperature of the material rises up;

(B) Constant magnetic field cooling: a cold thermal heat source is provided to cool the material to low temperature;

(C) Adiabatic demagnetization: magnetic field is removed away from the material in an adiabatic condition, and temperature of the material goes down; and

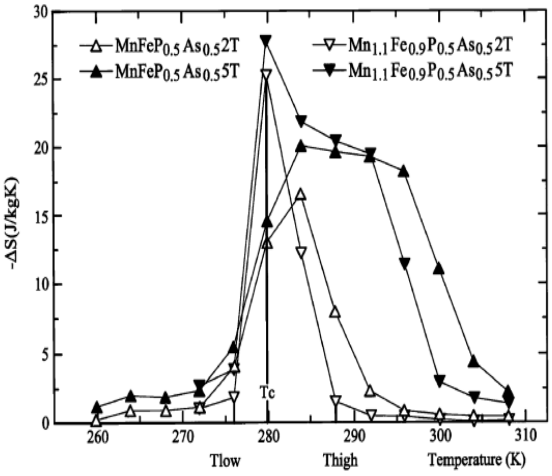
(D) Zero magnetic field heat absorption: a hot thermal heat source is provided to heat the material.

For cooling application, the process (D) is used to cool the environment. For heating application, the process (A) is used to warm the environment.

From this, we can know that the magnetic entropy change of MCEM is relative to the $(\partial M/\partial T)$. The larger $(\partial M/\partial T)$ of the material is, the larger the entropy change is, which will induce larger cooling capacity of magnetic thermal cycles. For the magnetic cooling (heat pump) application, the magnetic field is chosen to change the magnetic phase of MCEM, and the result is the change of magnetic entropy and eventually the change of temperature. The more largely the magnetic moment changes, the larger cooling capacity will be achieved.

When dealing with heat – power conversion, the thermal energy is chosen to change the magnetic moment of the MCEM, and the result is the power generation. For most of the MCEM, as the heat is applied to the MCEM and the temperature pass through the Curie temperature, the magnetic moment will change from high to low. Assume that a magnetism device with MCEM has been designed and allowed the magnetic flux flowing through the MCEM. When the thermal energy is applied to the MCEM and change its magnetic moment, the magnetic flux will be changed due to the magnetic moment change.

The magneto caloric effect material (MCEM) is not only suitable for the magnetic refrigeration application, it also suitable for the reverse processing which is the heat –power conversion application.



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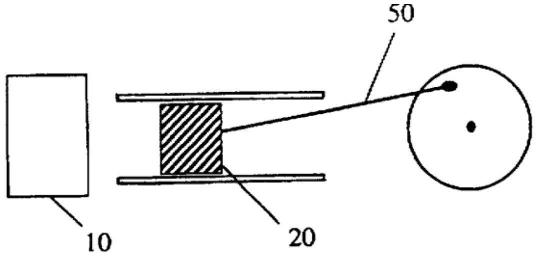
When a MCE material is subjected to magnetic field, large magnetic property (magnetic moment) changing occurs over relatively small temperature changes near the Curie temperature. At 2T magnetic field strength, the magnetic phase changes completely when the changing temperature (around 12 Kelvin) is between T low and T high. If a heat source is 10 Kelvin higher than T_c, it will be enough to change the magnetic moment from high to low. Taking the fig. as an e.g. the Curie temperature of the material is 280 Kelvin, the hot heat source of 290 Kelvin and cold heat source of 275 Kelvin will be enough to change the magnetic moment between T high and T low

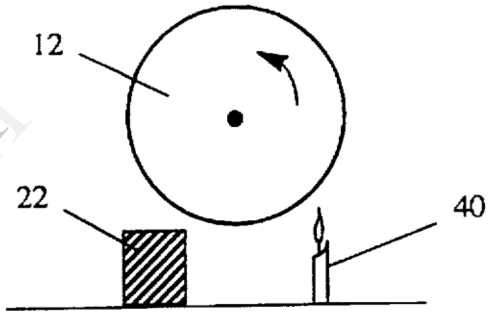
3. DESCRIPTION

Magnetic heat engines



A simple reciprocating engine is shown in fig in which a magnet (20) is constrained to move cyclically over a limited distance from a magnetic medium (10) by a crankshaft attachment (50). The engine is analogous to a conventional gas engine, with the magnet (20) serving as the piston. The medium becomes magnetized when the magnet approaches it, and demagnetized as the magnet recedes. The medium is thermally isolated for the adiabatic steps, by means not shown in fig, in synchronization with the motion of the magnet (20).

As the magnet (20) approaches the medium (10), the medium gets magnetized and tends to warm up. The medium is simultaneously cooled to maintain the temperature, and its entropy decreases. This corresponds to the isothermal magnetization. In the adiabatic portion the medium is thermally isolated while being magnetized further so its temperature rises. The isothermal demagnetization is then performed by adequately heating the medium as the magnet is withdrawn. The medium is not heated while the magnet continues to recede, so the demagnetization drops the temperature back to original stage.



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This fig. shows a non –reciprocating engine, a simple “magnetic turbine”, in the sense that the working medium moves continuously, with the various thermodynamic steps occurring simultaneously in different parts of the systems. A wheel (12) with a paramagnetic rim constitutes the stator, and a magnet (22) applies a magnetic field over part of the rim close to the magnet. Since the magnetic susceptibility deceases with temperature, the warmed portion of the rim is less attracted to the magnet (22) than the cooler region on the other side of the magnet. The differential susceptibility results in a torque, which causes the wheel to spin in the direction shown, from the magnet to the heat source. This thermodynamic conversion of heat to kinetic energy of the medium is used in magneto caloric power generation.

Since the rim is not specially cooled to maintain the lower temperature as it approaches the magnet (22), this simple turbine deviates significantly from the Carnot cycle and has a much lower efficiency. A variant of this design uses a wheel with a ferromagnetic rim. The heating must be sufficient to reach the Curie temperature (700 C, for iron. 20 C, for gadolinium) above which the rim becomes paramagnetic, thus providing a large change in susceptibility.

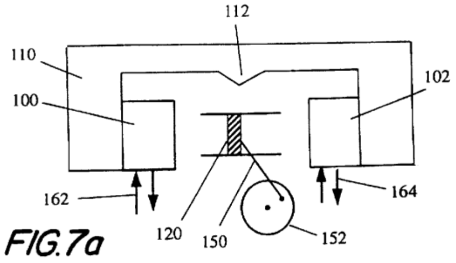

FIG.7a

FIG.7a shows a reciprocating magnetic engine using two elements (100,102) made mostly of a magnetic working material, and moving permanent magnet (120). The magnet (120) functions as the "piston", being constrained to move linearly between the engine elements (100,102). A ferromagnetic block (110) confines the magnetic flux. The block has a small center pole (112). The flux tends to concentrate between the engine elements and the center pole. When not operating, both the engine elements are cold, and the magnet will rest in stable equilibrium on one or the other side of the center pole (112). The magnet (120) is connected to a crankshaft (150) to transmit power to a wheel (152).

The engine elements (100,102) can be heated and cooled independently as described below. The engine operation begins with heating the element closer to the magnet (120), which increases its reluctance, so the magnet is now attracted to the other side of the center pole (112). The heating is then switched to the other side, while the first elements cools, to move the magnet back to the first element. The operation is analogous to a typical steam engine, in which the piston is pushed in either direction by steam.

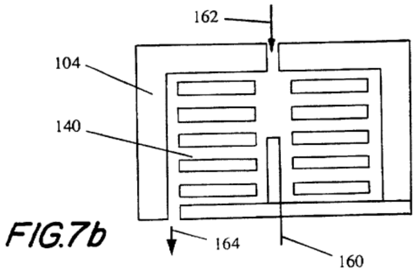

FIG.7b

The engine elements (100,102) may be designed for internal or external combustion. An internal combustion engine element might consist of a block of the working magnetic medium (140), as shown in fig. 7b for heating the element, a gaseous air-fuel mixture (162) is injected into pipe (140) embedded in the medium, and ignited by an electric spark mechanism (160) at a strategic position within the element so that the heat spreads rapidly through the embedded pipes in a short time compared to the mechanical motion of the magnet. For e.g. at 50 Hz (=3000 rpm) operation, the combustion and the heating should be completed in 1ms. For cooling, the burst gases are flushed out (164) by injecting cool air and then a fresh charge of air –fuel mixture. The internal combustion element functions as (Otto) engine.

An engine element with embedded pipes can be used with external combustion. The element is heated by injecting a hot fluid, and cooled by injecting a cold fluid. Note that most of the heat is removed as work done during demagnetization. Calculation for reciprocating engine

Let the working elements (100,102) be made of soft iron. At 5 Hz, 0.1 T applied field variation, the saturation power density is over 4 kW/liter. With a backoff-cure-efficiency factor of 0.4 the engine can yield up to 1.5kw/liter. If the working elements are of 1cm^3, the maximum power is about 3 kW.

Electromagnetic heat engine

A magnetic engine is although not very advantageous over a gas engine at the same frequency with respect to power density.

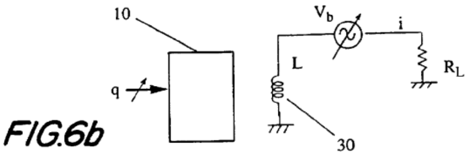

FIG.6b

But similar figures are applicable to the completely stationary electromagnetic engine as shown in fig.6b. using an internal combustion element constructed as in fig.7b and containing 1 liter of soft iron to serve as its magnetic medium (10), the electromagnetic engine can potentially generates up to 1.5 kW at mere 50 Hz from heat without using moving parts or thermodynamic fluid. Since it can conceivably be operated at 10 or 200 Hz instead, this electromagnetic engine can potentially yield 3 kW or 6 kW respectively. Incidentally, a 100Hz or 120 Hz is preferable for operating at the common a.c. supply frequency of 50 or 60 Hz respectively.

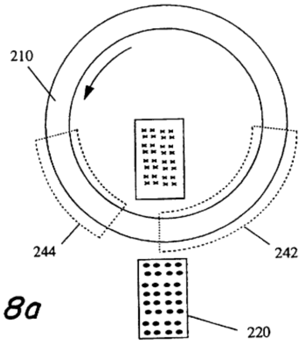

FIG.8a

The electromagnetic turbine of fig. 8b uses a horizontally mounted ring (210) of a solid magnetic working medium spinning through a coil (220), which is connected to an electrical load circuit and an auxiliary electric source to setup the load current.

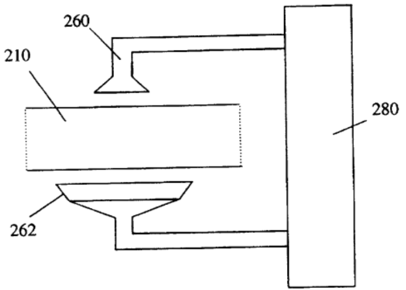

FIG.8b

A heat exchanger (242) heats the ring immediately as it emerges from the coil, and a second heat exchanger (244) cools it as it enters the coil. The hot exchanger may built as shown in fig. 8b, in which a liquid (260) carrying heat from a furnace (280) is simply poured on the ring and collected below by a pan (262). The cold heat exchanger would use a liquid coolant in like manner. In high power application, the heat exchangers may use water for cooling, and a liquid metal for heating, with a nuclear reactor replacing the furnace.

It should however be noted that the ring (210) is not really the magnetic circuit for the coil (220), because the engine operation depends on each portion of the ring becoming magnetized as it approaches the coil, and the becoming demagnetized as it recedes. Consequently, the magnetic circuit must be completed, possibly through stationary ferromagnetic segments, outside of the ring medium, such that the flux can enter or leave the ring in the region of the heat exchangers, where the magnetization is intended to change the most for ideally following the Carnot cycle.

Advantages:-

1. This Electromagnetic engine overcomes the limitation on speed due to mechanical operation in prior magnetic engines thus providing higher power densities.

2. It is generally useful over prior art heat engines because it eliminates moving parts including those in the a.c. reciprocating embodiments that of the medium.

3. At sufficiently high operating frequencies, electromagnetic heat engines can become useful for refrigeration at ordinary temperatures thus providing an alternative to the fluid refrigerants in use today.

4. Though magnetic refrigerators have been employed in cryogenics application, their non contact nature has not been particularly useful because of the mechanical motion required. Electromagnetic engines do not allow the non contact nature to be better exploited. Since the medium need not move, nor have particular shape for optimal operation.

5. At the high power end, electromagnetic engines are likely to be simpler to design, construct and control the prior art gas engines and steam turbine s apart from their unique and no-movement operability. (For e.g. spacecraft power generators cannot involve mechanical means for converting the heat from an onboard reactor, and frequently depend upon thermocouples giving about 4% efficiency.)Electromagnetic engines address one end of this conversion problem viz. eliminating intermediate mechanical form while potentially providing useful power densities .The forgoing calculations show than if a high power thermal switch be available for operating at 400 Hz, a completely solid state electromagnetic engine can typically provide about 25KW /liter of softly medium.

6. Electromagnetic engine may be used in conjunction with alternative means of cooling and heating. For instance cryogenic magnetic refrigerators are operated only after the temperature has been lowered to 10K or less.

7. Likewise, synchronous cooling is not limited to CMOS integrated circuits, but is equally applicable to any system potentially generating periodic or predictable dissipation, including digital circuits.

Even superconducting circuits, particularly those using high T_c materials, are known to produce some dissipation and are possible candidates for synchronous cooling.

4. CONCLUSION

Magnetic heat engine converts heat to coherent power which may be electricity or mechanical power very efficiently and with no byproducts. We can also apply the same concept of magnetization and demagnetization for heating and cooling purposes. By the use of this technology the degradation of environment due to use of refrigerants can be avoided. The magneto caloric effect material (MCEM) is not only suitable for the magnetic refrigeration application, it also suitable for the reverse processing which is the heat –power conversion application. Future advancement in this technology is desirable as it can revamp the field of refrigeration and air-conditioning.

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