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Use of Smart Electromagnets in Magnetic Refrigerator to Design an Efficient Refrigerator

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***Abstract*— Modern society largely employs refrigeration for several uses. Starting from domestic, commercial, industrial, for human comfort such as comfort air conditioning, to marine and transport applications. Printing industries, chemical industries, oil refineries, ice plants, and even more countless applications. Refrigeration is an inseparable part of human life. Most commonly used systems are the Vapor Compression cycle (VCC) based. Although being used mostly, the VCC has certain drawbacks. Involving poor performance at partial load and has moving parts in compressor, hence wear and tear, refrigerant leakages being harmful to human life as well as the environment and many more. The only way to overcome this problem is green refrigeration i.e. magnetic refrigeration. Magnetic refrigeration works on magneto caloric effect. It doesn't cause any harm to the environment. However, its basic design involves the use of rotating permanent magnets to continuously shift the magnetic field to achieve the desired effect. Use of rotating magnets consume power and even power is lost to overcome friction. The best way to tackle the problem is the use of electromagnets. The electromagnets can be turned on/off supported by a controlling circuit. This will eventually reduce the input power and gradually help in increasing the efficiency.**

***Keywords*— Magneto-caloric effect, adiabatic magnetization, adiabatic de-magnetization, electromagnetism**

I. INTRODUCTION

Refrigeration, as it is defined the process of removing heat from a body or confined space, with the aid of heat removal device also referred to as a refrigerator. A refrigerator works on a refrigeration cycle. Air refrigeration, Vapor compression cycle, vapor absorption cycle, thermo electric refrigeration, vortex tube, steam jet refrigeration system and many more cycles are developed and used accordingly. Out of which, the vapor compression (VCC) cycle is most commonly used.

Although being a mature technology, the VCC systems still use HCFC refrigerants, which in turn contribute in Earth's ozone layer depletion. However, in some countries, HCFC refrigerants are being replaced by HFCs, which prove friendly to ozone layer.

But the systems using HFC are less efficient. HFCs have an advantage of being ozone friendly, but they have large global warming potential.

So we need to focus on clean, green, eco friendly and more promising technologies. Magnetic refrigeration can be answer to our problem.

II. MAGNETIC REFRIGERATION

Magnetic refrigeration works on the principle of magneto caloric effect. According to which, if a suitable material is brought in contact with changing magnetic field, temperature change is observed. So it involves a process of magnetizing and demagnetizing the material.

The working material has its atoms randomly aligned. When it is magnetized, the atoms try to re arrange themselves in a straight path in the direction of magnetic flux. While doing so, these atoms collide with each other, due to which, heat is generated and magnetic entropy decreases. In the second part, if the material is demagnetized, and kept isolated, so that no energy is allowed to re migrate into the material, now in the absence of magnetic field the atoms try to get into random position, as they were originally. While doing so, they absorb the heat produced earlier during magnetization and magnetic entropy increases [1]. Due to this, the overall temperature of the material drops and it cools down.

Gadolinium and its alloys have no magnetic or thermal hysteresis, so they are best considered for magnetic refrigeration. [2] Gadolinium is a rare-earth metal with atomic number 64 and mass number 157.25.

i. Group- Lanthanides(rare earth)
ii. Block- f
iii. Melting point- 1313°C
iv. Boiling point- 3273°C
v. Density- 7.90 gm/cm^3

III. CYCLE

This cycle is analogous to Brayton Refrigeration cycle but with increase and decrease in magnetic field, instead of change in pressure.

Here, the working material is introduced to a magnetic field. The cycle basically involves four processes.

i. Adiabatic magnetisation
ii. Isomagnetic heat transfer
iii. Adiabatic de-magnetisation
iv. Isomagnetic heat absorption

IV. EXISTING MAGNETIC REFRIGERATORS

i. The magnetic system of Steyert

It was a system with rotating refrigerant, based on Brayton cycle which implemented a porus magneto caloric material in the form of ring. The basic concept was, the ring will rotate first from the low magnetic field and then from high magnetic field. [3]

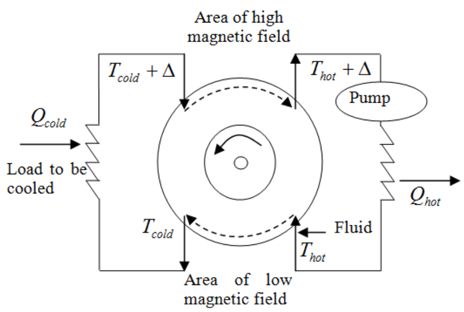

Fig. Schematic representation of the Steyert's magnetic system.

ii. The magnetic system of Kirol

This system was based on Ericsson's cycle and had a rotating machine. The magnetic field was produced by permanent magnets. During one cycles, four processes were performed and a ΔT of 11K was achieved.[3]

iii. The Spanish device

This was developed by a team of Polytechnic university of Catalonia in Barcelona. A ribbon of gadolinium (99.9%) fixed on plastic disk an immersed in fluid (olive oil) was used as the working substance. The magnetic cycle was achieved by rotation of plastic disk and its interaction with a magnet. A temperature span of 1.6 -5K was obtained for a magnetic field of 0.3 -0.95T. [3]

iv. The Japanese system (2006-2007)

The Japanese system uses a rotary valve and a magnetic field of 0.9 T. This design helped improve COP. [3]

v. The Canadian system

In University of Victoria, Canada (2007), another refrigerator was developed with rotary permanent magnets. This system led to a maximum ΔT of 13.2K.[3]

Including these and various other systems have been developed by researchers worldwide. All of these run on a rotating permanent magnet mechanism. This mechanism involves a motor, which means input power is more. Moreover, there are certain friction losses in case of a motor. It also involves a separate and expensive repair. So, if somehow we could eliminate the motor, indirectly, all of these problems will become obscure. And since, the motor is eliminated, the input power required will be less, which means, a definite increase in COP, keeping the refrigerating effect constant.

This is where the SMART ELECTROMAGNETS come into picture.

V. SMART ELECTROMAGNETS

Smart Electromagnets are not a rocket science. In simple, they can be defined as electromagnets with their own BRAIN. Their magnetic field, time for which they're magnetised, and various other similar factors are controlled by an on board microcontroller.

These Smart Electromagnets are further developed for application into magnetic refrigerator. Smart Electromagnets for Magnetic Refrigerator (SEMR). SEMR consists of following components:

i. Temperature sensors
ii. Microcontroller
iii. Control switches
iv. Electromagnet

The logic is simple, temperature sensors sense the temperature, and they send these signals to microcontrollers. Microcontroller is the brain. It processes the signals and accordingly sends output, to control switches. These control switches, in turn, control the electromagnet. They start the magnet; they can switch it off according to temperature inside the refrigerator.

i. Temperature sensors

These sensors detect a physical change in temperature, producing an analogue or digital output. Broadly classified into two categories : a. Contact temperature sensor, b. Non-contact temperature sensors.

These sensors are of following types,

1). Thermostat. 2). Bimetallic thermostat 3).Thermistor 4).Resistive temperature detectors (RTD) 5).Thermocouple. 6).Hot wire anemometer, etc.

ii. Microcontroller

A microcontroller is a small computer on an integrated circuit containing a processor core, memory, and programmable input/output peripherals.

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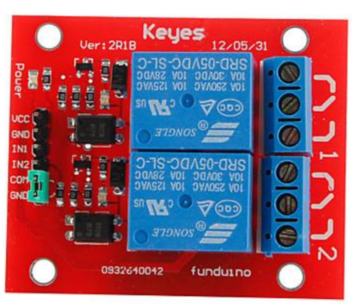
There are hundreds and thousands of types of microcontrollers out there in market with different specifications. But we are interested in ATmega328, which comes with an Arduino UNO board. Being simple, it is easy to program and to use.

iii. Control switch/ Relay switch

Relays are electromechanical devices, that use an electromagnet to operate a pair of movable contact from Normally Open (NO) to Normally Close (NC). They are most advantageous as control switches, because they consume a very less amount of power to do the controlling action.



iv. Electromagnets

It is a type of temporary magnet, in which magnetic field is produced by electric current. And the same magnetic field disappears when electric current is switched off.

It consists of a large number of closely spaced turns of wire that create the magnetic field.

The main advantage of an electromagnet over a permanent magnet is that the magnetic field can be quickly changed by controlling the amount of electric current in the winding.

VI. Modified Magnetic Refrigerator With Smart Electromagnets

A. The Basic Working

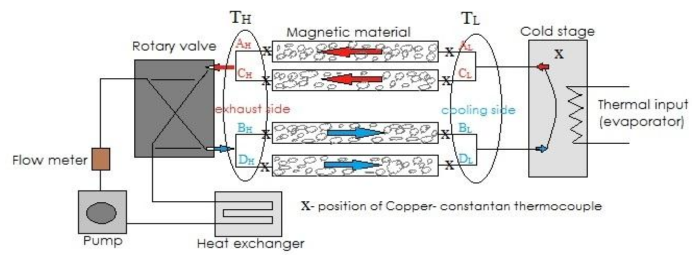


Fig. Constructional diagram

In this design, a rotary valve, 4 separate blocks of magnetic material, pump, heat exchanger, evaporator and a flow meter is used.

Each of the two blocks of magnetic material acts as one unit. The heat removal takes place in heat exchanger, the magnetisation and de magnetisation takes place in blocks and heat absorption takes place in evaporator.

Since there are 2 units, the cycle gets divided into 2 parts, i.e. in first part, A and C blocks are magnetised and B, D are demagnetised. So, the refrigerant flows through B and D, and extracts heat from evaporator. In second part, when B and D are magnetised, they heat up, but at the same instant, A and C are de magnetised, so they are cool. The rotary valve is then turned and refrigerant now flows from A and C and cools. And then the refrigerant circulates through evaporator and extracts heat.

Heat is absorbed from evaporator and pumped to atmosphere through heat exchanger.

B. Working of Smart Electromagnets

In this new improved design, as discussed earlier, 4 separate blocks of magnetic material are used. Out of which, A and C forms one unit and B and B forms second unit. The outer Fe yoke and electromagnets are permanently fixed. This system has no moving parts except for the rotary valve. In first part/cycle, electromagnet in (a) unit is switched on by microcontroller, and certainly A and C heats up, simultaneously, the microcontroller switches off the electromagnet in unit (b).

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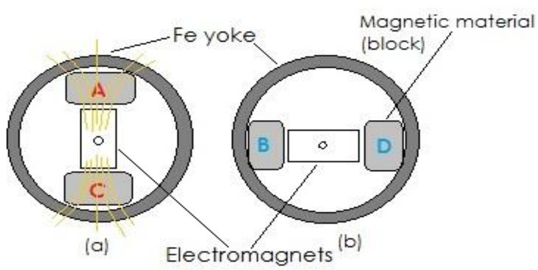
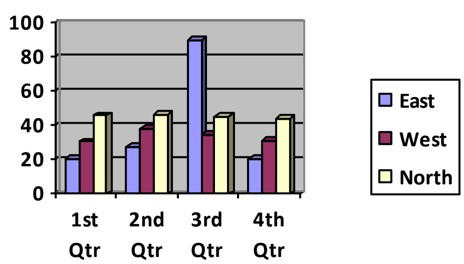


Fig. electromagnetic units

Hence, unit (b) de-magnetises and cools suddenly, now the microcontroller operates rotary valve and allows refrigerant to pass through unit (b) and then through evaporator.

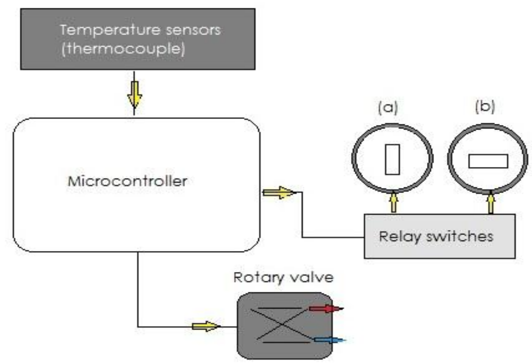
In second part/cycle, same process is repeated but, electromagnet in (a) is switched off and the one in (b) is switched on.

i. The Basic Working



The thermocouples will send temperature values to the microcontroller. This microcontroller will be pre-programmed to analyse these values and accordingly send output signals to relay switch. The relay will operate the electromagnets in unit (a) and (b) accordingly.

Also, after completion of one cycle, the microcontroller will send output signals to operate the rotary valve, which switches the path of refrigerants. The basic block diagram is as shown below.



ii. Advantages

i. This system replaces the old mechanism of rotating magnets.
ii. The only one moving component, i.e. rotary valve.
iii. Less number of moving parts means less wear and tear of the components.
iv. The use of motor, to rotate magnets is eliminated. This in turn, reduces the input power for same output.
v. Reduced input means more COP.
vi. This is more sophisticated system with the whole cycle divided into two convenient parts.
vii. The use of microcontroller makes the system smart. The same controller can be programmed to do other things, to make this system even smarter.
viii. Magnetic refrigeration is a clean and green technology.

iii. Dis-Advantages

i. The use of microcontroller and other related components makes the system technically complicated.
ii. With the use of two electromagnetic units, the overall size of system increases.
iii. The system may get affected by external magnetic field.

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VII. CONCLUSIONS

With the implementation of this system, surely the COP of magnetic refrigeration system will increase. And we can develop a new and efficient system.

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