PWM controller for thermoelectric devices used in a climatization system

Controlador PWM para dispositivos termoelectricos utilizados en un sistema de climatización

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ABSTRACT

The present work describes the development of an open loop temperature control system in a container through a Peltier Cell. The control consists of applying a PWM signal to the thermoelectric device, which controls the temperature in a range of 5 to 90 °C. A study was carried out to characterize the frequency and duty cycle of the PWM and thus determine the best operating conditions for the thermoelectric element. In addition, a power stage was implemented to change the supply polarity in the Peltier cell and, in this way, to be able to exchange the heating and cooling faces. The study carried out leaves the basis for implementing climatization system on a larger scale using thermoelectric elements in a novel and versatile way.

Keywords: Thermoelectrics, climatization system, PWM controller.

RESUMEN

El presente trabajo describe el desarrollo de un sistema de control de temperatura en lazo abierto en un contenedor mediante una célula Peltier. El control consiste en aplicar una señal PWM al dispositivo termoelectrico, que controla la temperatura en un rango de 5 a 90 °C. Se realizó un estudio para caracterizar la frecuencia y el ciclo de trabajo del PWM y así determinar las mejores condiciones de funcionamiento del elemento termoelectrico. Además, se implementó una etapa de potencia para cambiar la polaridad de alimentación en la célula Peltier y, de esta manera, poder intercambiar las caras de calentamiento y enfriamiento. El estudio realizado deja las bases para implementar el sistema de climatización a mayor escala utilizando elementos termoelectricos de forma novedosa y versátil.

Palabras clave: Termoelectricas, sistema de climatización, controlador PWM.

1 INTRODUCTION

The climatization systems have always been widely used, depending on the geographical area where they are located is the demand for cooling, heating or both depending on the time of year. These systems are in high demand and although they present good energy efficiency, it is seldom reflected on the negative impact on the environment that they may cause due to the use of some gases used for refrigeration that are highly polluting. That is why when looking for new fewer polluting alternatives and that both the cooling and heating systems can be incorporated in a single unit, thermoelectric systems appear as a solution. Thermoelectric are mainly known for the direct conversion of heat into electricity as thermoelectric generators (TEG). But they also present another effect known as the Peltier effect, which by circulating a current through them generates a temperature difference between both extremes, in this case it is called a thermoelectric cooler (TEC). TEC's have several advantages over conventional refrigeration systems, they are solid state refrigeration devices, wear is minimal due to no moving parts, they are reversible effect controlled by their polarization voltage, they do not use refrigerant gases that they are pollutants to the environment, among others.

Even though the thermoelectric effects present in some metals were studied since the early nineteenth century, the first known effect was discovered by the German physicist Thomas J. Seebeck discovered in 1820, later in 1834 the Peltier effect was discovered by Jean Peltier. Although both effects are always present, it was not demonstrated until in 1851 the Thomson effect was discovered by William Thomson (Lord Kelvin).

On the other hand, thermoelectric effects as mentioned in Priscila & María ^[1] thermoelectric devices are based on the fact that when certain materials are heated, they generate a significant electrical voltage. As can be seen in Figure 1 the electrons move from the hot end of the material to the cold end, creating positive and negative electrodes and with it the electrical voltage.

Figure 1. Representation of electrons as they move from the hot to the cool end. Retrieved from (Priscila & Maria, 2020)

Thermoelectricity relates three phenomena explained by Priscila & María ^[1] which are the Thomson effect, Seebeck effect and Peltier effect. The Thomson effect consists when a current flows through a homogeneous conductor of constant cross section where a temperature gradient has been established. To keep the temperature distribution unchanged, heat must be dissipated or extracted from the conductor. The Seebeck effect occurs when two different metals at different temperatures come into contact, forming a bimetallic union, an electromotive force is generated between both sides of the union, causing a current density or a potential difference. Peltier effect occurs when a current is applied through a bimetallic joint, to keep the joint temperature constant, heat must be delivered or extracted, depending on the direction of circulation. This phenomenon has practical application in small refrigeration devices, having the advantage of not having moving parts to wear out.

To better describe Blancarte Lizárraga ^[2] says that it is used more widely through the so-called Peltier cells: By feeding one of these devices, a temperature difference is established between the two faces of the Peltier cell, this difference depends on the room temperature where it is located, and the body that we want to cool or heat. If we look at Figure 2, it can be seen that it is practically composed of two semiconductor materials, one n-type and the other p-type, joined together by a copper sheet.

Figure 2. P-type and n-type materials inside a Peltier cell. Retrieved from (Blancarte Lizárraga, 2001)

If the positive power supply polarity is applied to the material side N and the negative polarity is applied to the material side P, the copper plate on the upper part cools, while the lower one heats. If the

supply polarity is reversed, that is, the negative polarity is applied to the n-type material side and the positive polarity to the p-type material side, the heat / cool function is reversed: the upper part heats and the lower part cools.

Furthermore, Blancarte Lizárraga ^[2] tells us that there are Peltier cells with different dimensions and powers, isolated or not isolated depending on whether or not there is a thin layer of ceramic material above and below the two surfaces, necessary to isolate the copper sheets of the different thermoelectric junction; consequently, these two surfaces can be supported on any metallic plane without the need for insulators, in Figure 3 the structure of a cell is shown.

Figure 3. Peltier cell structure showing the cool side and hot side. Retrieved from (Blancarte Lizárraga, 2001)

Peltier cells have a ceramic insulation with a very low thermal resistance, so the loss of temperature by transfer is negligible. The operating diagram of this thermoelectric device can be seen in Figure 4.

Figure 4. Operation of a Peltier cell; the temperature difference between the faces is 70°C. Retrieved from (Blancarte Lizárraga, 2001)

The heat or cold that a Peltier module can generate is specified by the thermal difference (thermal difference) indicated by its manufacturers.

In Blancarte Lizárraga ^[2]: a thermal jump of 70 degrees means that, if the hot side of the cell has stabilized at a temperature of 45 degrees, on the cold side there is a temperature of $45 - 70 = -25$ degrees.

On the contrary, if the hot side only reaches 35 degrees, on the cold side there is a temperature of 35-70 = -35 degrees.

The TECs are manufactured with p-type and n-type tellurium and bismuth semiconductors because the maximum efficiency is between room temperature and approximately 200 ° C. Thermoelectric effects involve the correlation between electrical currents and voltages against heat and temperature transfers, these are the main virtues that make thermoelectricity have a place in the world of refrigeration according to Rubio Ramirez, Marthey Lizarazo, & Emilio, ^[3].

Experimental setup.

A commercial Peltier cell model TEC1-12706 was used (see Figure 5), which is polarized with a voltage of 12 V and has a current consumption of 6 A. If the Peltier cell is directly polarized, the face with the code will decrease its temperature, while the opposite face will increase. This is because the device exhibits a reversible phenomenon, that is, the temperature of the faces is dependent on the polarization voltage.

Figure 5 Peltier cell model TEC1-12706 power supply 12V at 6A

A system was developed to characterize the temperature of the Peltier cell, as shown in Figure 6. It consists of a variable voltage and current source, thermocouples as a temperature sensor on both sides of the cell, multimeter to monitor voltage and current, a Peltier cell equipped with a heat sink coupled to a dc fan as an extractor, all coupled to a 0.023 m³ thermal container. The heatsinks were slotted to embed the thermocouples and have a better contact and therefore obtain an optimal measurement.

Figure 6. Temperature monitoring with 12V powered system

Characterization of the Peltier cell with different conditions

The characterization of the behavior of the Peltier cell for its study was divided into two cases, both were carried out for periods of time of 15 minutes and samples were collected during each minute. In the first case, the cell was supplied with a nominal voltage of 12 V and its response was obtained for both cooling and heating. In the second case, a pulse width modulation (PWM) was used, varying the duty cycle in 10% increments, and maintaining a frequency of 50 Hz, a heat extractor fan is continuously used during the cooling stage to improve heat dissipation from the outer face. Later during the heating mode, the external fan was kept off. Once the performance results were obtained, the best conditions were chosen where maximum cooling and heating is obtained by the Peltier cell. Table 2 summarizes the best operating conditions.

Table 2. Trials with different conditions to feature the Peltier cell.

TEST NUMBER	TERMS				
	Thermal Paste	Fan	Applied Voltage	Inside the container	Remark
1	Yes	Yes	12V	Cold	
2	Yes	No	12V	Hot	
3	Yes	Yes	9.6V	Cold	PWM 80%
4	Yes	No	10.8V	Hot	PWM 90%

2 RESULTS

The tests were carried out with an initial temperature on each face of 23 °C. In the first case (test 1), the final temperature on the hot side was 40 °C and on the cold side, 12.2 °C. At the end of the test, the temperature difference between the hot and cold side of the cell was 27.8 °C, Fig.7. Subsequently, the polarization voltage was inverted (test 2) repeating the same procedure and as a result it was obtained that

the highest temperature was 88 °C while the lowest was 22 °C, the final gradient of temperature between both faces of the cell was of 66 °C, Fig. 8.

Figure 1. Thermal behavioral graph of the Peltier cell. Shown with an initial temperature of 23°C on each side, the lowest final temperature was 12.2°C and the highest was 40°C.

Figure 2. Behavioral graph, the cell heats up inside the container. The initial temperature of the hot side was 21°C and the cool side was 24°C.

For the second case (test 3), to reduce the internal temperature of the container, the control of the Peltier cell was implemented by means of a PWM with a duty cycle of 80%, which is equivalent to providing 9.6 V average, producing a minimum temperature of 5 °C, while the higher temperature stabilized at 30 °C. The difference of temperature in both faces of the cell was 25 °C. The initial temperature on the cold side was 20 °C and on the hot side 20.7 °C. With these results show the good behavior of the device for solid state cooling applications, Figure 9 shows this graph.

The last test consisted of heating the container by supply the Peltier cell with a 90 % duty cycle equivalent to 10.8 V average. The initial temperature on both sides of the cell was 29 °C, after 15 minutes the maximum temperature inside the container was 64.8 °C, while the temperature of the cold side (outer face) was 24 °C, Fig.10. Reaching a temperature difference of 40.8 °C between both faces of the cell.

Figure 9. Behavior with a duty cycle of 80%. The final temperature on the cool side was 5°C and on the hot side 30°C. It showed a temperature difference of 25°C.

Figure 3. Behavior graph with a final cool temperature of 24°C and a final hot temperature of 64.8°C. The difference was 40.8°C.

With this comparison we can observe the thermal jump of the Peltier cell. According to manufacturer's data, the Peltier cell has a thermal jump of 70 °C, according to Wilfredo ^[4] in practice

there are heat transfer losses between the cell and its cooling fin, which makes it difficult to achieve the thermal jump, Fig. 11.

Finally, the stabilization time of the system was observed (see Figure 12). It can be seen that the time does not vary from one test to another, but the fastest response was in test 3 when the cell was fed with the PWM at 80% to lower the temperature inside the container. This can be compared with test 1 since, in these two tests it was required to decrease the temperature; the stabilization time was slower in test 1 because it was supply with the maximum voltage value, on the other hand in test 3, its power was controlled with a PWM whose operating frequency is 50 Hz and the average voltage of 9.6 V.

Figure 12. Bar graph comparing the stabilization time in each of the tests. Tests 1 and 3 lowered the temperature inside the container, while tests 2 and 4 increased it.

3 CONCLUSIONS

With this work, it is shown that thermoelectric systems are an excellent option in solid state refrigeration. In the same way, when presenting a reversible phenomenon, it is possible to use the same device both to decrease and to increase the temperature, producing a wide control range, which can be from 5 °C to 88 °C.

It was found that the thermal jump varies due to the correct extraction of heat from the thermoelectric device, which also depends on external factors such as the ambient temperature and the correct sealing of the container.

The use of a PWM is a good option as a power controller for a Peltier cell used for cooling, it allows the operating temperature to be kept low and thus facilitates adequate dissipation of the hot face. However, when increasing the temperature, it does not seem like the best option, although it allows an adequate operation of the device, it is not possible to reach the same temperature levels as when it is used with its nominal polarization.

This work seeks to create a prototype that can control the temperature to be used as cooling or heating to make small low-consumption temperature control systems, which could be scalable to larger dimensions.

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