



25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COBEM2019-2143

TEMPERATURE CONTROL SYSTEM USING PELTIER MODULES

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Abstract. *In the present work an experimental technique is proposed for the measurement of the thermal efficiency of thermoelectric pellets based on Peltier effect. Thermoelectric devices are solid state devices which directly convert thermal energy to electrical energy and vice versa. A microcontroller is used to acquire data from the DS18B20 sensor (sensor used to measure temperature), where an analysis is made to characterize the best way to obtain Peltier cell cooling. The objective is to design and elaborate a temperature control system with temperature sensor and Peltier pellets as actuator. This system should take into account both heating and cooling of the chamber where it will act. The Ziegler and Nichols method was applied in the open loop system to obtain the PID parameters to be used in the controller for both heating and cooling processes. Simulations were performed in a MATLAB tool and in SIMULINK to obtain, respectively, a model for the plant response and the step response of the designed controllers. The results present first order and a second order transfer functions for cooling and heating models, respectively, and the designed controllers maintain the stability without overshoot.*

Keywords: *Peltier effect, PID Controller, Temperature Control*

1. INTRODUCTION

This work proposes a procedure to minimize temperature variations during the density measurement of any liquid in a closed system, for temperatures ranging from 10 to 60°C, through the elaboration of a control system and construction of the chamber prototype where it will act. For this, the PID (combination of proportional, integral and derivative controls) temperature control will be adopted, which works together with a temperature sensor. The actuator used in this process to keep the temperature constant and ideal for the experiment will be the Peltier module. Also known as a thermoelectric module, its operation is based on the "Peltier Effect" which was discovered in 1834. When a current is applied, the heat moves from one side to the other, causing one side of the pellet to become cold and the other hot. It is important to note that these modules do not "consume" heat, so it becomes necessary to use a heat sink to remove this heat.

There are several benefits associated with using Peltier modules: (1) solid state construction; (2) precise temperature control; (3) vibration free operation; (4) carbon free; (5) no acoustic or electric noise; (6) performance in any environment or gravitational orientation; (7) operates at zero gravity. In the case of temperature control, their application is wide and can be implemented in various areas, such as in an oven, thermal cycle, CPU coolers, heaters and coolers mini-coolers and heaters.

The characterization of a fluid includes density measurements using a densimeter for different samples at different temperatures. These measurements must be performed within a chamber containing both the sample and the densimeter, where the temperature must be kept constant. In this way, this research has two objectives: Development of a temperature control system with temperature sensor and Peltier modules as actuators. This system should take into account both the heating and the cooling of the chamber where it will act. Construction of chamber prototype with the temperature controller.

Clearly, the controller-actuator system developed in this project can be used in future to perform other types of experiments involving temperature control, which requires only the adequacy of the chamber and the number/arrangement of Peltier modules. For example, in a greenhouse, in industries, it is necessary to use this control to keep the products intact, without loss of their physicochemical properties, chemical processes, among others.

2. DEVELOPMENT

The initial focus of the research is the study and test of the thermal efficiency of thermoelectric modules (Peltier effect). An experimental technique was proposed to measure and compare the heat transfer capacity of the cell. A controller for the data acquisition of the temperature sensor DS18B20 was used, where an analysis of the heat transfer of the system was carried out with the Peltier, using fins and a cooler. Through experiments, the differences in temperature variation in the system with Peltier modules associated in parallel and in series that were verified. In addition, the efficiency was analyzed by the insertion of a device that increases the rate of forced heat transfer in the system. The goal is to get the best response from the Peltier module using the most of its energy when developing a prototype.

The prototype was constructed with insulation material (styrofoam boxes and rubberized plates E.V.A). In Fig. 1 it is possible to visualize the cooling/heating system and the chamber that simulates the prototype. A Peltier module model TEC1-12706 was used in conjunction with a cooling-heating system as shown in Fig. 1. The material used to prevent heat exchange with the environment was an aluminum-coated styrofoam box (12 liters).

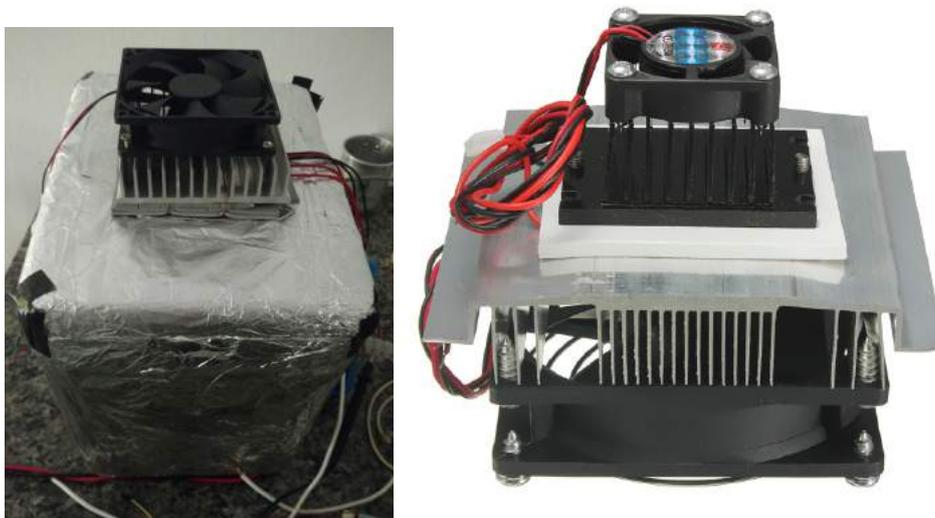


Figure 1. Prototype of temperature control system with a Peltier cell used in the cooling test. Available from: Author.

2.1 Thermoelectric modules and Peltier effect

Jean Charles Athanase Peltier (1834) observed peculiar thermoelectric effects when introducing small external electric currents into a Seebeck thermocouple ¹ Seebeck (1965) of bismuth and antimony. Jean Charles Athanase Peltier was investigating peculiar thermoelectric effects when he introduced small external electric currents in a Seebeck bismuth-antimony thermocouple. Their experiments have shown that when a voltage difference is applied to the junction of two different metals in one direction, the junction cools, absorbing heat from the medium in which it is located (Moura and Almeida, 2014). When the polarity of this voltage is reversed, the junction heats up, heating the medium in which it is. In general, the Peltier effect is related to the reversible emission or absorption of heat. The phenomenon occurs when an electric current crosses the junction between two different metals, where in one of them there is an increase in temperature while in the other a decrease occurs.

Thermoelectric modules (TEC), as shown in Fig. 2, are small active devices for heat dissipation, based on the Peltier effect. Similar to thermocouples, which has as its operating principle the Seebeck effect. Unlike the thermocouples, a series of semiconductors (doped with Bi₂Te₃), grouped in pairs, are used in the construction of these modules, thus obtaining a greater effect. These joints are placed between two plates, so that when in operation, heat is transferred from one face to another.

Based on this effect, the Peltier module is a thermoelectric device that has two main faces, where one side cools and the other heats according to the direction of the current passing between its terminals. The heat flux is absorbed or generated in a reversible manner and depends on the current direction (PINDADO, 2008). The heat transfer results in a cold face and a hot face. In addition, TEC can be used for both heating and cooling by switching the voltage polarity applied to its Raghav *et al.* (2013) terminals. In general, the Peltier effect is related to heat emission or absorption, and the heat flux depends on the current direction applied.

¹Seebeck effect is related to the conversion of thermal energy. When the junction of two different metals in a closed circuit is exposed to different temperatures, a e.g. is generated.

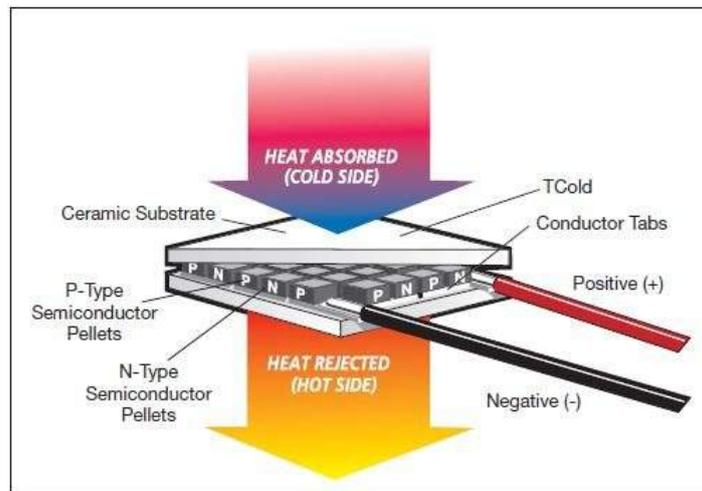


Figure 2. Peltier thermoelectric module. Available from: Glentoy (2018)

2.2 Components

The list of components used in the data acquisition circuit is shown in Table 1.

Table 1. List of components. Available from: Author.

Components	Amount
Arduino Uno	1
Protoboard	1
Resistor 4.7k	1
Sensor DS18B20	1

Figure 3 shows the connection scheme of the DS18B20 temperature sensor to the Arduino UNO card.

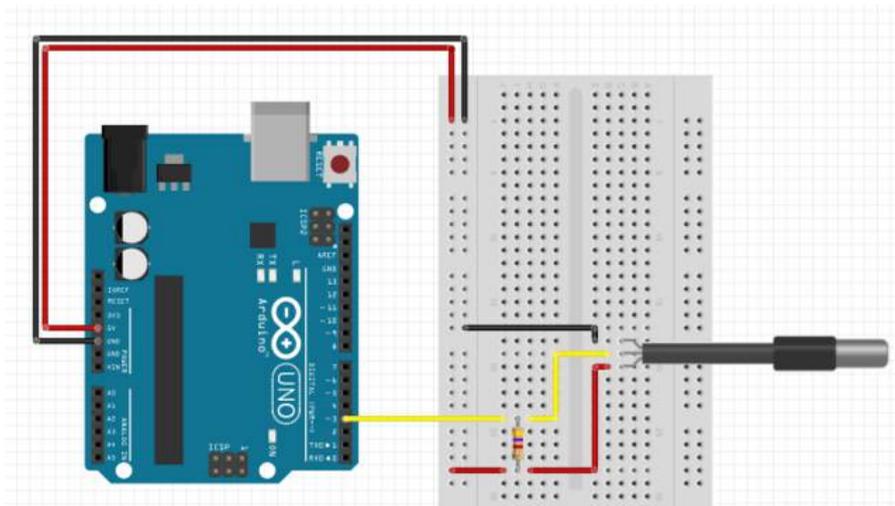


Figure 3. connection schematic Available from: <https://portal.vidadesilicio.com.br/sensor-de-temperatura-ds18b20/>

2.3 Controller

The controller acts in this process, supplying the a constant temperature in a chamber. There are rare cases in which the use of these controllers is not necessary, where the process is perfect and free of disturbances or external influences that would harm the project. By closing the system loop, with the controller and the process, it is possible to create a feedback, always receiving information about how the system's behavior is, as shown in Fig. 4. If there are any errors during the process or not, the in relation to the output.

To design this controller, the following points must be taken into account:

- Transient performance requirements;
- Performance requirements in steady state.

The PID temperature control combines the so-called proportional with the integral and derivative controls (PID), shown in Fig. 4. Thus, it allows the system to operate within a proportional band in the same way as a proportional control does but with two characteristics that improve overall temperature regulation. Proportional feature allows control to respond to current conditions and adjust accordingly. Full value takes into account the sum of recent events (past proportional control rhythms) and the derived value in turn determines the appropriate reaction based on the rate at which the past rhythms are changing. Combined, all three use current data, past data, and the rate at which data is being changed to define a specific temperature control algorithm thereby compensating for the temperature error between the process variable and the set point while maintaining a constant temperature.

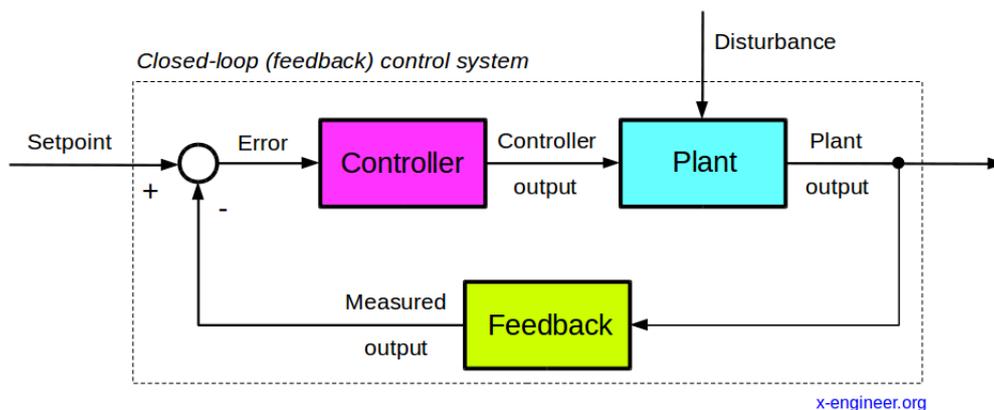


Figure 4. Generic system in closed circuit. Available from: <https://x-engineer.org/graduate-engineering/signals-systems/control-systems/on-off-control-system>

The practical tuning method developed by Ziegler and Nichols (1942) is used to determine the gains of the derivative integral proportional controller (PID), more specifically, the reaction curve method (also called open-loop method). This procedure has the advantage that there is no need to know the system model. Tuning consists of adjusting the controller from the respective system when it is subject to specific inputs; the values determined allow the PID controller gains to be calculated.

The reaction curve method consists in the evaluation of the open loop system response to obtain the characteristic curve parameters, given an amplitude and reference input. The curve obtained in the response should have an S-shape (otherwise the method is not valid) as shown in Fig. 5.

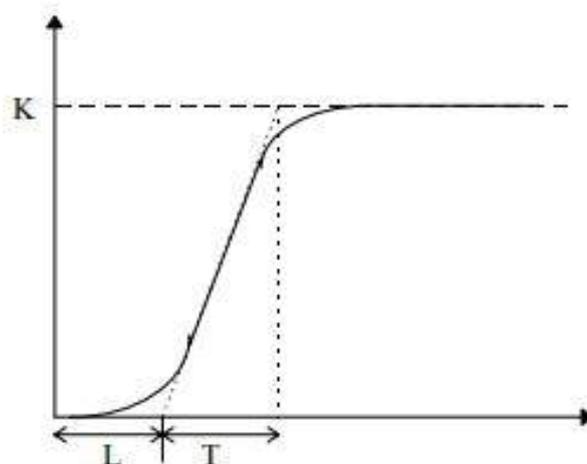


Figure 5. Reaction Curve Available from: Lourenço (1996).

This curve can be characterized by two constants, the delay L and the time constant T , which can be determined with the aid of the tangent line passing through the turning point of the curve. At the points where the tangent intersects the abscissa axis and the horizontal line with ordinate K , we get the delay time L and time constant T , respectively Ogata

(2011). After determining the values, we can calculate the controller parameters PID, following the Table 2. The PID parameters are respectively: controller path gain K_p , controller's integrator time constant T_i controller's derivative time constant T_d .

Table 2. PID controller parameters. Available from: (Ogata, 2011)

Control	Parameters		
P	$K_p = L/T$		
PI	$K_p = 0.9T/L$	$T_i = L/0.3$	
PID	$K_p = 1.2T/L$	$T_i = 2L$	$T_d = L/2$

3. RESULTS

Figure 6 is the result of the Peltier module cooling and heating efficiency test. The test consists of applying a step input to the open loop plant and observing its behavior over time. The ambient temperature recorded by the DS18B20 sensor and a mercury thermometer was 29°C . On cooling test minimum temperature achieved was 24°C , resulted in a difference of 5°C . The heating test show that Peltier is an excellent heater, the final temperature achieved was 62°C .

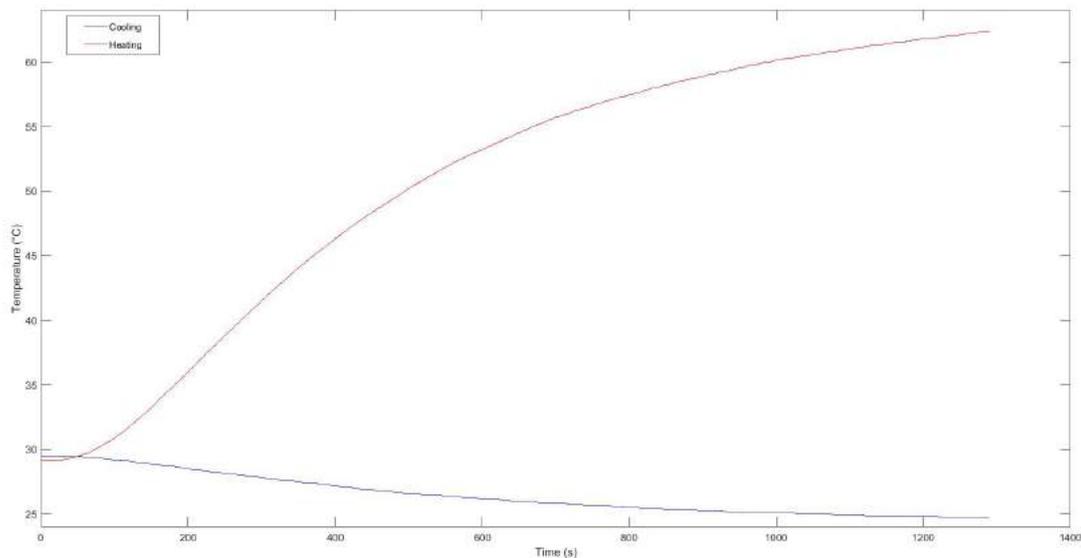


Figure 6. Peltier cell cooling-heating test. Available from: Author.

The MATLAB System Identification Toolbox tool (an app for constructing mathematical models of dynamic systems from measured input-output data) was used to construct a model that approximates the plant response. Figure 7 shows a good approximation of the model to the plant.

A time-domain curve fitting is used to determine the values of parameters in the first order time model for the cooling action, Eq. (1); the adjustment of the model resulted in an approximation of 94%. On the other hand, in the heating action it was found a second order model, Eq. (2), which indicates that the Peltier cell has a different behavior compared to cooling; the result presented an approximation of 99%. The transfer function (expressed on frequency domain s) obtained, respectively, for the cooling, H_c , and heating, H_h , responses were

$$H_c = \frac{-8.0624}{1 + 550.33s}, \quad (1)$$

$$H_h = \frac{21.392}{(1 + 21.392s)(1 + 90.23s)}. \quad (2)$$

The found models allow the evaluation of the controllers action found in the PID tuning open-loop method. The SIMULINK software was used as shown in the Fig 8 to simulate the step response of the designed controllers.

From Fig. 9, we note that the plant parameters for tuning are $L = 35$ and $T = 835$. Table 3 shows the controller parameters by applying the tuning rules.

For the first order system found in the cooling action, the P or PI action control has the most satisfactory response, however the control action of the two controllers is very close due to the high value of the integral time constant (Fig. 10

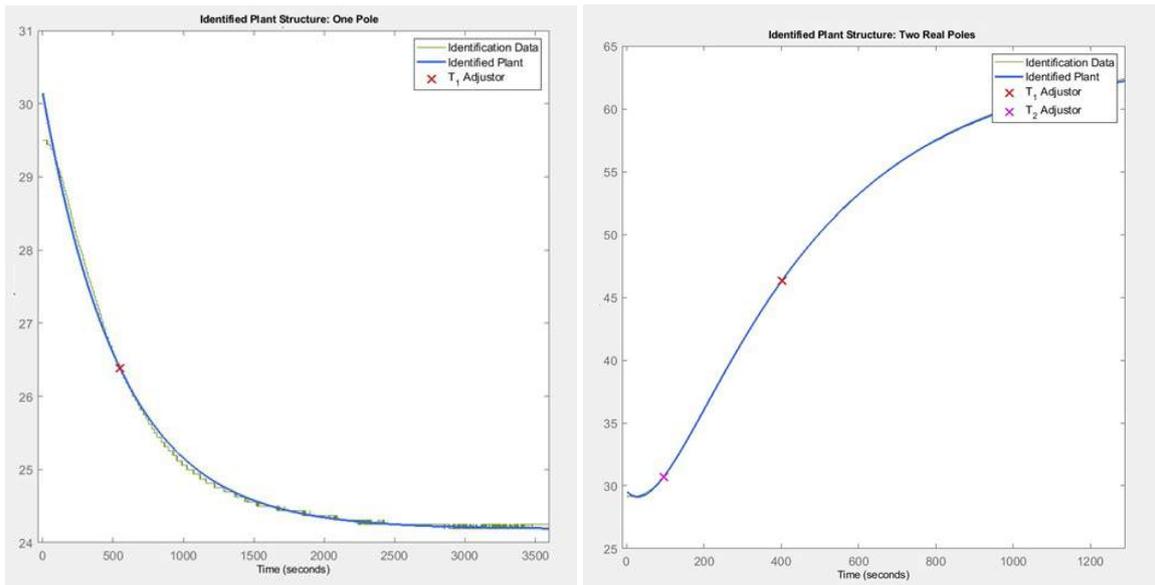
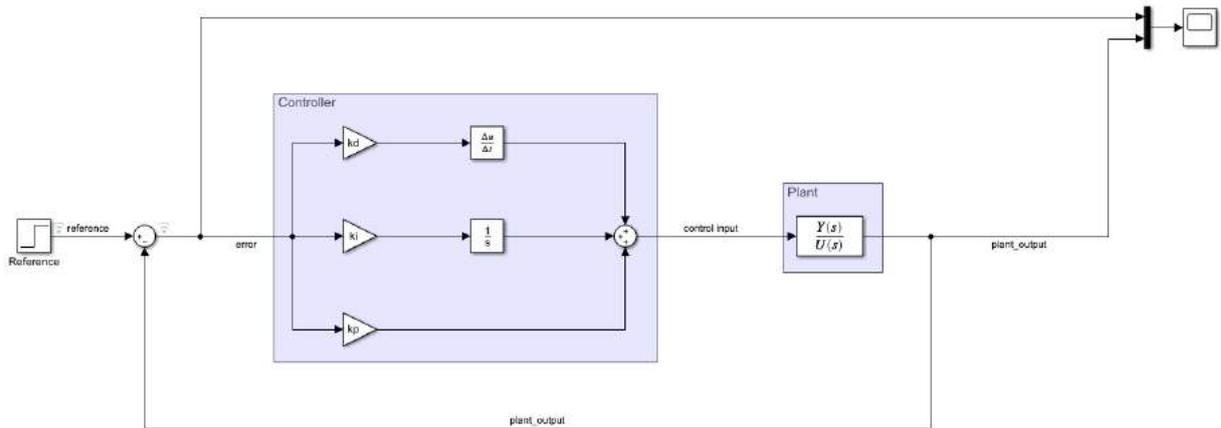


Figure 7. Identified plant structure from (left) cooling and (right) heating.



SIMULINK.jpg

Figure 8. PID schematic on SIMULINK. Available from: Author.

Table 3. PID project parameters for cooling. Available from: Author.

Controller	Kp	Ti	Td
P	23.85714	inf	0
PI	21.47143	2783.333	0
PID	28.62857	70	17.5

left). The PID controller has bad dynamics so it will be dropped. The manufacturer of Peltier cells recommends that the cell should not change the temperature often at rates much higher than one centigrade per second. In this case, the system response can be accelerated to a fine tune. It was decided to adopt a proportional action controller with the adjusted gain to obtain a three times faster acceleration dynamics $K_p = -60$ (Fig. 10 right).

Figure 11 below shows the step response of the heating system. Note that the tuning parameters are respectively $L = 70$ and $T = 630$.

Table 4 shows the controller design values for heating, the process is a second order dynamics, so the PID controller is the closest to the desired dynamics presented in Fig. 12 left. The PID control response has no overshoot and is able to follow the reference without wobbling. For faster dynamics, a proportional gain adjustment was made $K_p = 150$ (Fig. 12 right).

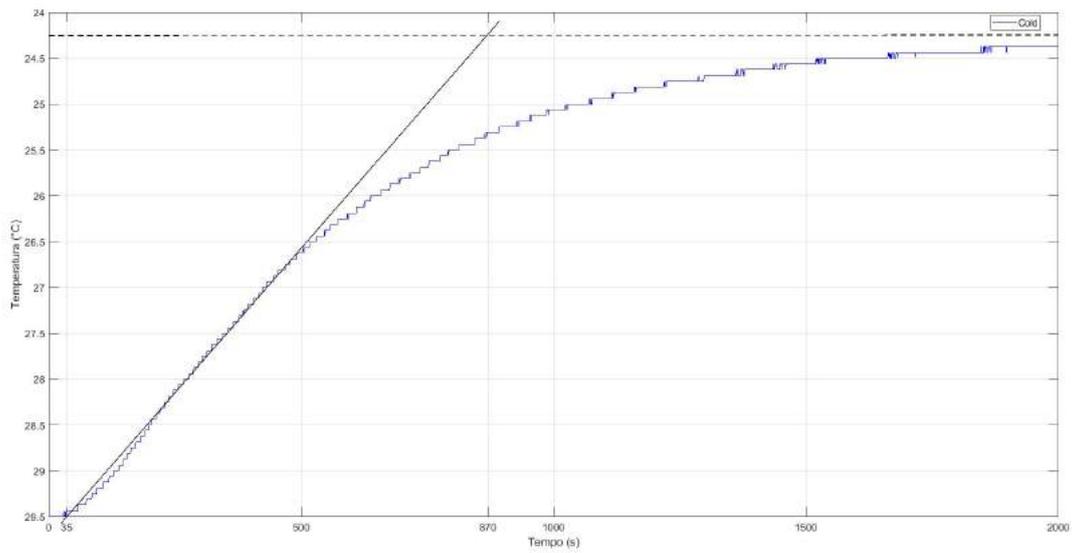


Figure 9. Step response from cooling. Available from: Author

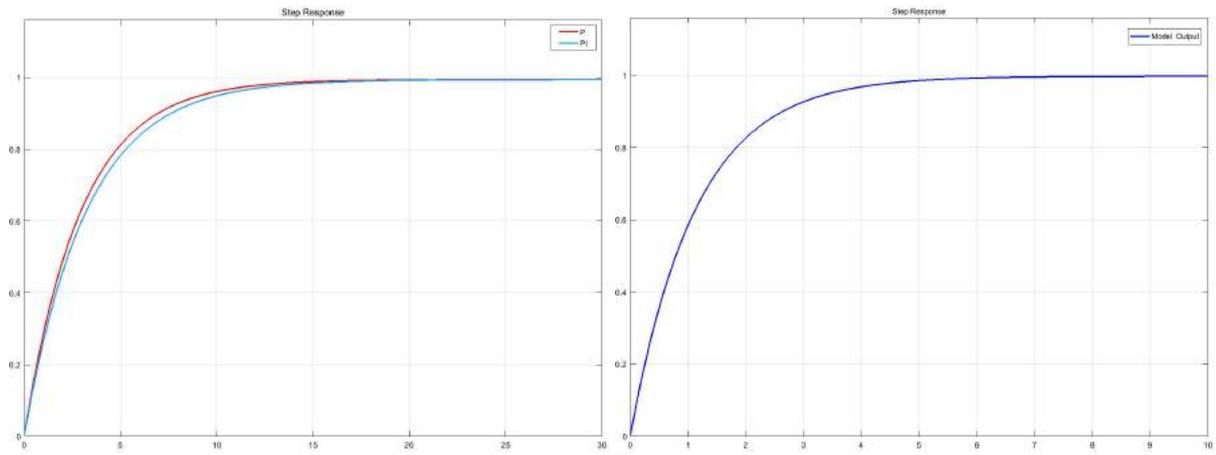


Figure 10. Cool Model Step response of (left) controllers P, PI and (right) designed controller for cooling system. Available from: Author.

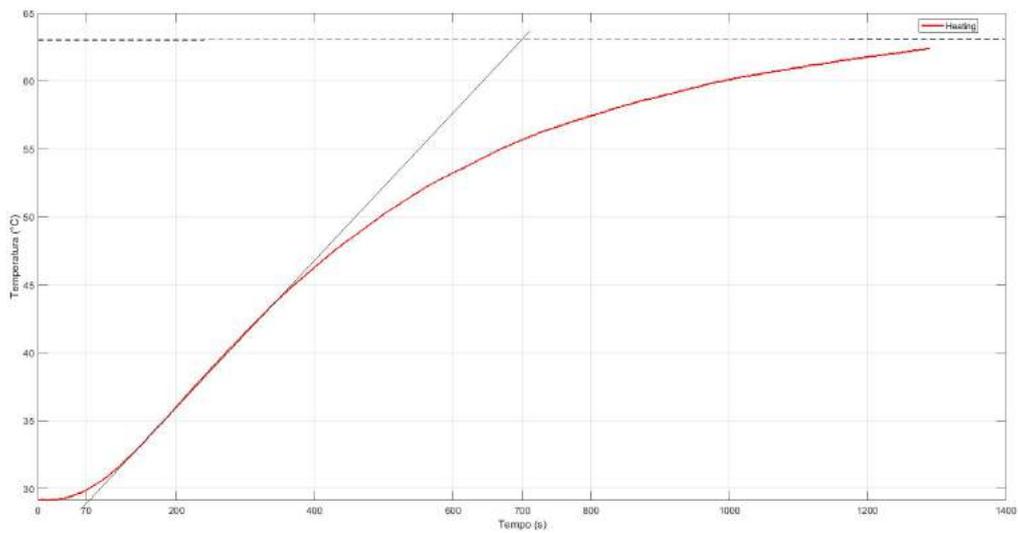


Figure 11. Step response from heating. Available from: Author.

4. CONCLUSION AND PERSPECTIVES

The PID controller design for Peltier thermoelectric modules has been presented in this study. The proposed PID controller was simulated and the effective performance system has been validated via MATLAB and SIMULINK softwares. To achieve control performance the design was based on a Ziegler-Nichols tuning method. The system process was modeled with the aid of the System Identification Toolbox app provided by MATLAB. The identified process resulting from the cooling action was a first order model and the heating action was a second order model. The results from the simulation show that the controller can reach stability and satisfies the set point specification with a speed response without overshoot.

Temperature can be controlled with Peltier modules to obtain a precise actuation system. Peltier cells require a stable DC current for optimal operation. The easiest way to do this is to control the supply voltage, however, this type of operation can shorten Peltier insert life if it is used for a long period of time. Nagy and Roman (1999) performed tests on the Peltier cells observing changes on the AC resistance of this device; they implemented PWM at different frequencies on Peltier for 192 hours. The result of the experiment indicates that during this period there are no significant changes to interfere with their performance. A safe and practical way will be adopted in the next steps by considering a PWM with an L inductor in series, so the Peltier cell will be powered by the medium current without stress with different voltage levels.

In order to achieve a controlled temperature in the range of 10°C to 60°C in the prototype, the results indicate that the required minimum temperature can be reached by adding more power to the cooling system, it means by adding more Peltier cells to the system.

Table 4. PID project parameters for heating. Available from: Author.

Controller	Kp	Ti	Td
P	9	inf	0
PI	8.1	2100	0
PID	10.8	140	35

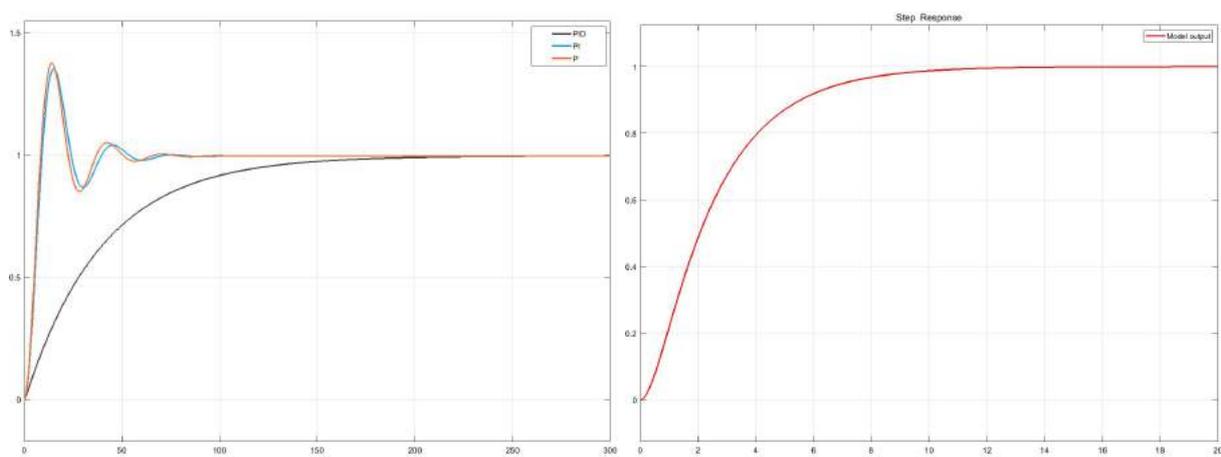


Figure 12. Heat Model Step response of (left) controllers P, PI, PID and (right) designed controller for cooling system. Available from: Author.

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