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Tesis

**Electromechanical device for temperature control
of internal combustion engines**

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Electromechanical Device for Temperature Control of Internal Combustion Engines

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Abstract. Internal combustion engines are the most commonly used engines in the automotive world. However, these engines lack an overheating prevention system against cooling system failures when they exceed their normal operating temperature. Less experienced drivers (users) usually do not notice overheating until the engine stops, generating economic expenses in engine repairs. As such, this paper describes the design and construction of an electromechanical device to prevent engine overheating. This device is installed in a vehicle and operates independently from the electronic control unit (ECU); it records the coolant temperature and controls air admission to the engine of the vehicle in which it is installed. In addition, a new Arduino-based card will receive signals from a temperature sensor as input and process them according to its programming. Then, it will send signal outputs to the actuators: a servomotor, monitor, LED display, and buzzer. To control the intake flow, a butterfly valve is used with the servomotor. This valve partially or totally restricts the engine airflow, based on the temperature programmed for the Arduino, thus protecting the engine from overheating.

1. Introduction

The overheating of internal combustion engines causes lubrication problems due to lowering oil viscosity levels. Further, some parts can be deformed. Some factors that might cause the generation of high temperatures in a water-cooled internal combustion engine are as follows: obstruction of the air circulation holes of the radiator, water pump failures, radiator-fan-belt breakages, radiator water leaks, stuck thermostat, and other cooling system related issues [1]. Because engines may reach impressive internal temperatures of up to 2000 °C, the cooling system is designed to disperse part of the temperature produced by the combustion process of the engine. Therefore, it must absorb, circulate, control, and dissipate temperature [2]. Prompted by competitive market needs, the modern automotive industry faces the problem of having to develop and implement in its products the changes produced by technological evolution in amounts of time that are becoming increasingly smaller and with greater budget constraints. In fact, only modeling and virtual simulation can help engineers to respond with the required swiftness and at the lowest costs possible. Apart from boosting responsiveness, modeling and simulation tools offer the advantage of streamlining changes and evaluations of the proposed new designs [3]. Water cooling means that vehicle cylinders are housed inside a casing that is filled with water circulated through a pump. Then, water is cooled when it passes through the radiator blades. It is important for the engine-cooling liquid to not be ordinary water because combustion engines work



regularly at temperatures exceeding the boiling temperature for water [4]. Additionally, feedback control systems are called closed-loop control systems. In practice, the terms feedback control and closed-loop control are used interchangeably. In a closed-loop control system, the actuation error signal is fed to the controller. This error is the difference between the input and feedback signals (which can be the output signal or based on a function of the signal output and its derivatives and/or integral functions). The error is fed into the controller to reduce the error and force the system output to return to an expected value [5]. Temperature sensors are also called thermistors. The resistance of conventional metal-oxide thermistors decreases non-linearly, which means that when temperature increases, their resistance decreases. Such thermistors have negative temperature coefficients (NTC), although there are also thermistors with positive temperature coefficients. The resistance change for each degree of temperature alteration is much greater than the change that occurs with metals [6]. When dosing air to the engine, cylinders are filled by aspiration, during the piston downstroke while the intake valve is open, or by previously compressing air, which is called overfeeding. Unlike a diesel engine, the Otto engine can only regulate loads by the amount of mixture introduced and burned in the cylinder. Since the dosing must be continuous, the per-cycle work depends directly on the air mass. In other words, the power developed is a function of mass airflow.

Airflow is regulated using a butterfly valve placed in the intake manifold and operated by the driver when the accelerator pedal is pushed. The butterfly valve creates a variable pressure drop so that upstream, the existing pressure is approximately equal to the atmospheric pressure, while downstream, it will always be lower [7]. Invented by James Watt in the eighteenth century, the butterfly valve is one of the most popularly used valves that currently exist as its design facilitates its installation, maintenance, and operation, thus generating savings and benefits for a company. It has a body, which comprises a disk that rotates 90° around an axis and controls the flow of liquids or gases [8].

Arduino is an open-source electronic prototype platform based on flexible and easy-to-use hardware and software. It was created for students, designers, and anyone interested in developing interactive objects or environments. Arduino can interpret the environment by receiving its inputs from a wide variety of sensors and can modify its environment by controlling devices such as transducers, lights, and motors. The board's microcontroller is programmed through the "Arduino Programming Language" (based on Wiring1) and the "Arduino Development Environment" (based on Processing2). Arduino projects can be stand-alone or they may interface with software running on a computer, tablet, or mobile device. The plates can be assembled by hand or ordered preassembled. The software can be downloaded for free. The reference hardware designs are available based on an open-source license so they can be adapted to different needs [9].

2. Methodology and design

2.1. Proposed design

The device is designed with two components: an electronic component and a mechanical component.

2.1.1. The electronic component records, processes, and provides immediate signal responses to actuators. Before assembling the circuit, it was necessary to use the Proteus software to create a simulation that would determine whether the electronic system was working properly. Then, the electronic layout will be created to assemble the electronic system, as shown in Figure 1. The proposed electronic card is based on an Arduino module. The voltage supply is 5-V direct current, which will be regulated using a voltage regulator. Further, the NTC temperature sensor will emit signals as input for the Arduino module, which is in charge of processing the information and of providing responses as output signals to actuators. The responses can include that the servo motor will move at a certain angle and activate the relay to press the buzzer at the maximum temperature programmed. An LCD monitor (screen) will display the current coolant temperature and position of the servomotor.

With all these data, the design of referred components for the assembly is executed. With the layout, a card can be burned with the circuit designed to place the components based on the Arduino module

used. Then, the components will be welded using tin and a soldering iron to prevent them from moving.

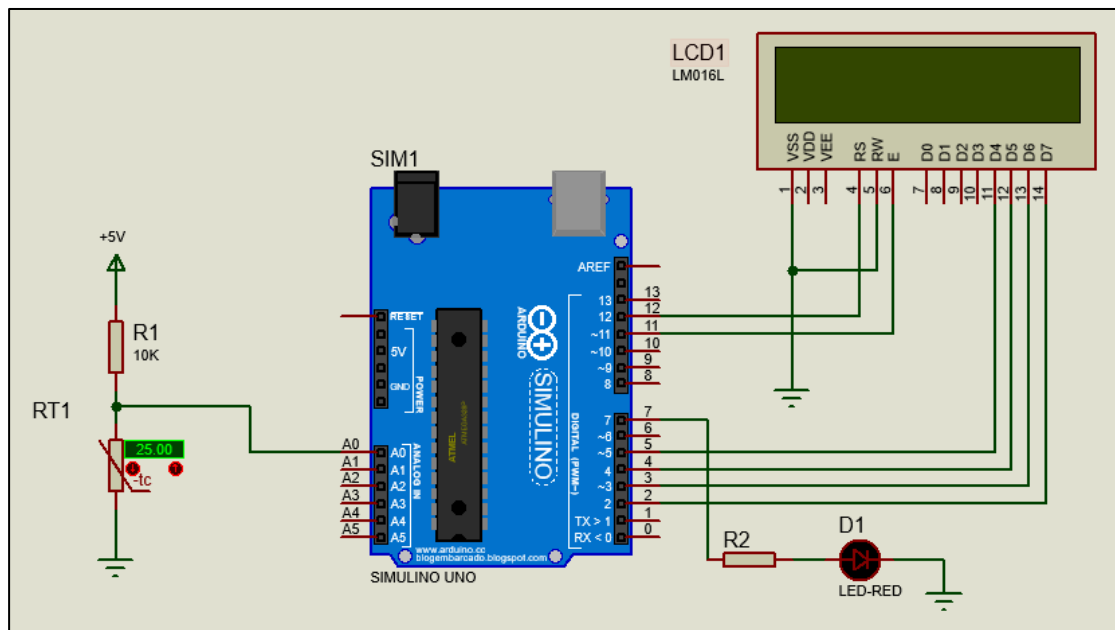


Figure 1. Simulated circuit in Proteus

2.1.2. *The mechanical component* is included in the design of the butterfly valve to restrict airflow, for which it is necessary to calculate cubic feet per minute (CFM) operating motor parameters (cubic inches per min) and the valve torque.

CFM calculation

- Data: for a 1300-cc 2nz engine
- Compression Ratio = 10.5 to 1
- Maximum power = 63 KW (84.5 HP) 6000 rpm
- Maximum torque = 121 Nm (12.3 kgf.m) 4400 rpm

Table 1. Calculation of airflow for internal combustion engines

Number of cylinders	Cubic centimeters	1,300	
Revolutions per min (RPM)	Enter the highest expected value	6,000	
Volumetric efficiency	Non-turbo gasoline engine	3	0.8
Results	CFM		110
Liters per min of air required for a maximum speed			3,120

Note: the calculation is based on a maximum consumption for a turbocharged gasoline engine. The values of certain electronic controls can increase this air value by up to 2.

With maximum values to increase the design factor

$$CFM = 110 \text{ ft}^3/\text{min} \quad Q = 0.0519142195 \text{ m}^3/\text{seg} \tag{1}$$

Speed and flow

$$A = \pi r^2 = \pi 0.0295^2 \text{ m}^2 = 2.64 \text{ m}^2 \tag{2}$$

Flow

$$Q = VA$$

Calculation of V (speed)

$$V = Q / A = 0.05 / 2.64 = 0.018 \text{ m/s} \quad (3)$$

Valve simulation

The butterfly valve will be installed at the intake inlet between the filter and vehicle's throttle body. In Figure 2, the airflow can be noticed when the valve is completely open, and the atoms are heated when passing through the valve.

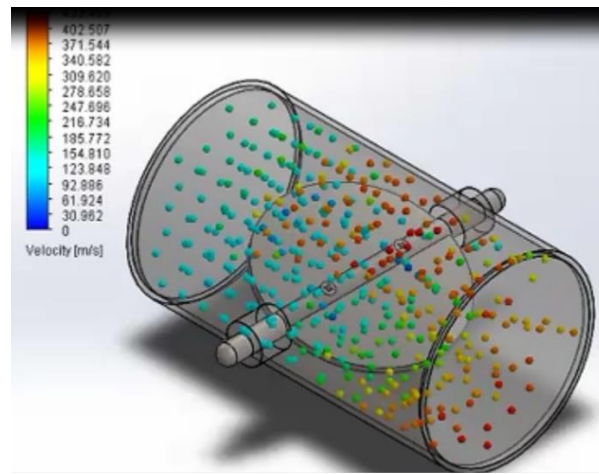


Figure 2. Valve completely open

This principle will be used to restrict engine airflow to control overheating. The servomotor will be installed on the valve shaft and controlled by the Arduino module because the temperature range of an engine, for normal operations, is 82 °C–96 °C. At 82 °C, the thermostat opens; if the temperature is lower, it closes. In this way, the temperature is maintained above 82 °C. When the temperature rises to 96 °C, the fan is activated and cools the radiator. Thus, the engine maintains its working temperature range [10]. To ensure that temperature is not exceeded (for a 0 °C–96- °C range), in its programming, it is requested for the servomotor not to move. In this case, the valve is left in a horizontal position and completely open. When the engine reaches 97 °C, the device works by moving the valve to the 45 ° counterclockwise position, restricting the airflow and partially reducing power and torque. If the driver was stepping on the accelerator to achieve the maximum speed and the engine was operating at a high number of revolutions, the normal operating temperature range would have been exceeded. It will not be possible to continue stepping on the accelerator owing to the lack of air, and when the engine temperature is lowered to its working range, it will return to normal. If the temperature increases (and reaches 98 °C–99 °C), the valve will move an additional 45 °, placing itself at 90 °. In this position, it will be completely closed, as shown in Figure 3. The engine will stop and be turned off owing to a lack of air. In this way, the device will fulfill its objective of stopping the mechanism and preventing the engine from overheating.

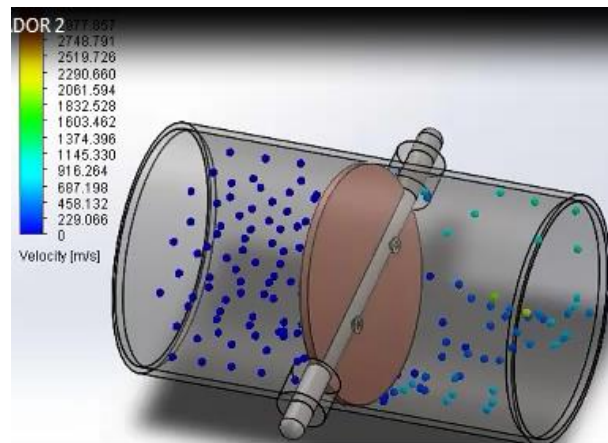


Figure 3. Valve close

When the engine cools and temperature drops to below 96°C , the engine will return to normal; the valve will open completely and the device will once again automatically work with the other components, thus fulfilling a closed-loop control with feedback. If the device was not installed and the water pump was not working, the engine would overheat at high temperatures. This is when the valve would perform the main functions for which it was designed: a perfect closure and ensuring that the axis is not deformed or broken. This is the reason why a static stress analysis was performed, as shown in Figure 4.

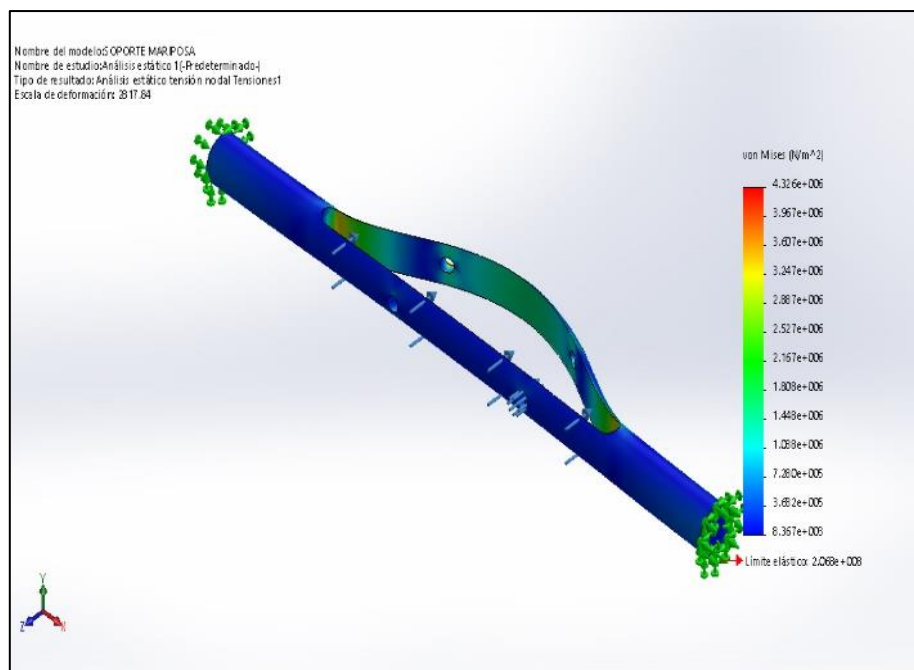


Figure 4. Static stress analysis

3. Results and analysis

An automotive scanner was required to read the temperature sensor, and a multimeter was used to experimentally obtain field data.

The temperature sensor is a negative-temperature-coefficient (NTC) sensor. When the temperature rises, resistance decreases.

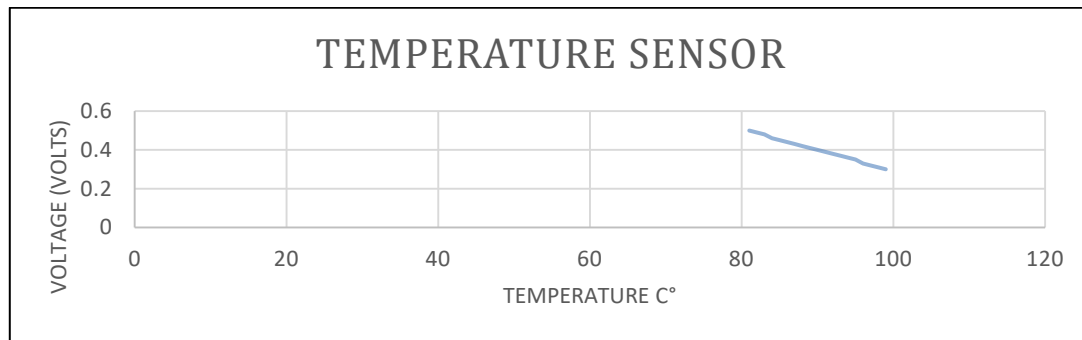


Figure 5. Temperature Sensor

The static analysis simulation software results for the butterfly valve shaft are as follows:

Table 2. Static analysis simulation software

Selections set	Units	Sum X	Sum Y	Sum Z	Results
The complete model	N	7.45058e-008	-3.85568e-007	0.999987	0.999987

As shown in Figure 5 and in the results from Table 2, the lowest resulting force occurs along the Z axis. Further, the simulation depicted in Figure 4 does not exhibit any red surface, which means that the axis has no stress and diameter and selected material are correct. The butterfly valve can be manufactured according to the designs produced by Solidworks and design parameters.

4. Conclusions

- Electronic components and their programming are the easiest parts, but the design of the mechanical component is slightly complex.
- Regarding the valve, programs such as Solidworks are quite necessary and useful tools for simulation and to draw up the layouts.
- When developing the device prototype, a set of processes and steps are listed for the project, which we have to follow as they are structured in a sequence.
- When designing the device, many factors, such as the engine shutdown, were taken into account. At first, this only involved a thermostatic switch and power cutoff relay in the ECU. However, after careful analysis, other problems might occur. For example, if the vehicle is traveling at a high speed and turned off at any moment, the brakes would not function properly owing to the vacuum booster produced by the engine that causes the brakes to become rigid. Steering, on many models, is hydraulically powered and if the engine does not work, the hydraulic steering system would not work either. These problems could cause very serious accidents. However, in terms of safety, the proposed design would not bring about such problems.
- When assembling the electrical components, we could not find a temperature sensor for the Arduino module in the market. Therefore, the module had to be tested using a sensor similar to the one used for the engine. This sensor worked well after a voltage divider was installed as a modification.

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