Application of Hall Effect Sensor in temperature control valve of automotive Internal Combustion Engine

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Abstract*— *The growing demand for new technological solutions in automobiles, often to replace mechanical with electromechanical solutions, seeks better system controls to improve fuel economy and reduce pollutant emissions, while also improving the comfort and safety of vehicle users. With the recent advances in microelectronics, many sensors are being used in unexpected applications, an example of which is the Hall Effect Sensor, which is increasingly used in vehicles due to its ease of application. The contribution of this work is the development of a temperature control valve (TCV) that replaces the thermostatic valve with a more accurate temperature control system, using a Hall Effect Sensor to control the flow of the engine cooling fluid. The implementation of the Hall Effect Sensor enables new functionality to the TCV, which previously had just two operative states (On and Off). In this way, it is possible to improve the temperature control of the combustion engine.

***Keywords*— Flow rate, Hall Effect Sensor, Magnetic field, Temperature control valve.**

I. INTRODUCTION

The use of new technologies in automobiles has led to a significant increase in sophisticated vehicle electronic systems, which are also called embedded systems. Analysts estimate that 90% of the innovations in the automotive industry are related to electronic systems [1], [2], [3], [4]. In recent years, new research has emerged to improve vehicle performance with respect to four main factors: safety, comfort, the economy of energy consumption, and reduction in gas emissions. This has spurred the development of new products, many of which are sensors [5], [6]. Sensors are devices installed at strategic points in the motor to record signals that are then analyzed by the motor control unit to determine which strategy to follow. According to Lopes [7], sensors must be located where the measurement is performed. Although some types of sensors need not be in contact with the object being measured, they must be located in the vicinity. Sensors, in general, are expensive and fragile and must be specially adapted to ensure their durability and reliability. The Hall Effect sensor has recently become a versatile option for applications within vehicles. Figure 1 shows some applications of Hall Effect sensor in automotive systems. One of the fundamental employments of the Hall Effect sensor in automotive frameworks is for the detecting of position, distance and speed. For instance, the precise position of the crankshaft for the firing edge of the sparkle plugs, the position of the vehicle seats and safety belts for air-bag control or wheel speed recognition for the anti-lock braking system.

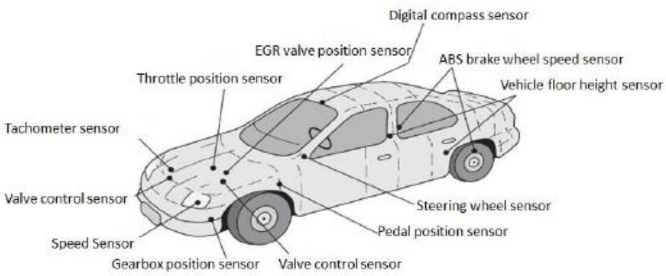

Fig. 1: Hall Effect sensors used in an automotive system

Many authors have considered the Hall effect sensor in an automotive system. For instance, Xiao et al [8] demonstrated a method of position detection for permanent magnet linear synchronous motors (PMLSM) by linear Hall-effect sensors. Based on finite element analysis of the motor's magnetic flux and considering the dimension limit of the motor in practice, the best mounting position of the sensor is given to eliminate the influence of the back iron and improve the accuracy of the detection.

Joo et al [9] implemented a device that can measure a small magnetic field by measuring a linear movement of the switching current by adding the spin Hall Effect to the

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abnormal Hall Effect of the perpendicular magnetic thin film. Nama et al (10) apply a smart Hall Effect sensor system used for sensing the rotor position in a 3-phase BLDC motor. The intelligent sensor system proposed allows the motor to continue working even when one of the Hall sensors is damaged and not working. Lalnunthari et al [11] present an interface between the Hall Effect flow sensor with Arduino to study the effect of pipe size on the frequency and rate of flow of the sensor. Hall Effect flow sensor is found to be largely affected by the attached pipe size at the inlet. Mercorelli et al [12] built a hybrid actuator composed by a piezo and a hydraulic part. A cascade PI-PID control structure for camless engine motor applications is considered. The idea of this contribution is using the advantages of both: the high precision of the piezo and the force of the hydraulic part. Piezo electric actuators are mostly used for precision positioning, despite piezoelectric actuators present nonlinearities, such as saturation, hysteresis and creep.

The contribution of this work is the development of a temperature control valve (TCV) that replaces the thermostatic valve with a more accurate temperature control system, using a Hall Effect sensor to control the flow of the engine cooling fluid. The implementation of the Hall Effect sensor enables new functionality to the TCV, which previously had just two operative states (On and Off). In this way, it is possible to improve the temperature control of the combustion engine.

This paper is organized as follows: Section 1 gives the general introduction of the topic. Section 2 gives a brief description of the Hall Effect sensor and the automotive cooling system. Section 3 presents the application of the Hall Effect sensor in the temperature control valve while section 4 provides the results and conclusion.

II. THEORETICAL BACKGROUND

2.1 Hall Effect Sensor

According to Xiao [13], the Hall Effect sensor is a magnetic-field sensor that is based on the effect discovered by Edwin Hall in 1879. This electrically isolated device can be applied to sense continuous and alternating currents of typically up to hundreds of kilohertz. Due to its simple structure and compatibility with microelectronics, a Hall device can be monolithically integrated into a fully integrated magnetic sensor and manufactured using conventional complementary metal–oxide–semiconductor (CMOS) technology.

When a conductor is crossed by a current and placed in a magnetic field, the voltage will be perpendicular to the current and field. This principle is known as the Hall Effect. When there is no magnetic field and the current distribution is uniform, no potential difference appears at the output. When a perpendicular magnetic field is present, a Lorentz force is exerted on the current. This force causes a disturbance in the current distribution, which results in a potential difference between the output terminals. This voltage is known as the Hall voltage (HV). The Hall voltage is proportional to the cross product of the current (I) and the magnetic field (B), as shown in Equation (1).

$$V_{HV} \propto I \times B \qquad (1)$$

The yield signal for straight (analogue) sensors is taken straightforwardly from the output of the operational amplifier with the output voltage being proportional corresponding to the magnetic field going through the Hall sensor (Figure 2). This output Hall voltage is given by Equation 2.

$$V_H = R_R(\frac{I}{t}) \times B \qquad (2)$$

Where:

V_H is the Hall Voltage in volts;

R_H is the Hall Effect coefficient;

I is the current flow through the sensor in amps;

t is the thickness of the sensor in mm;

B is the Magnetic Flux density in Teslas.

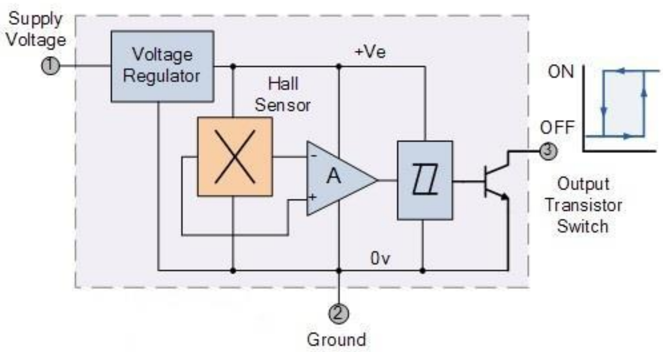

Fig. 2. Typical Hall effect sensor circuit.

Analogue sensors give a persistent voltage output that increases with a strong magnetic field and diminishes with a feeble magnetic field. In direct output Hall Effect sensors, as the power of the magnetic field expands the output signal from the amplifier will likewise increase until it starts to immerse by the cutoff points forced on it by the power supply. Any additional increase in the magnetic field will have no effect on the output but drive it more into saturation.

A Hall Effect device is basically a field-effect sensor. It requires an additional circuit to condition the signal and produces an output voltage usable for most applications,

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consisting of an amplifier stage and temperature compensation. A typical Hall transducer has a limited current peak, due to core saturation, and limited bandwidth (<1 MHz), although it can measure DC current. In addition, it is very sensitive to external magnetic fields. Hall Effect sensors operate mainly in closed-loop mode to realize better accuracy and greater dynamic range. These sensors are sensitive to the polarity of the magnetic field (north and south), as is the amplified output, which provides a voltage proportional to the magnetic field to which it is exposed. Saturation occurs in the amplifier, not in the Hall element, and will not damage the sensor [14].

Hall effect sensors are solid state gadgets that are becoming more and more popular since they can be utilized in a wide range of sorts of use, for example, detecting position, speed or directional movement. They are additionally a well-known choice of sensor for the gadgets designer due to their non-contact wear free task, their low support, a strong plan and as sealed Hall Effect gadgets are insusceptible to vibration, residue and water.

2.2 Automotive Cooling System

The automotive cooling system consists of the following main components: fluid passageways in the cylinder block or engine jacket, radiator, coolant pump, thermostat and expansion tank. Figure 3 shows a circuit diagram of the automotive cooling system.

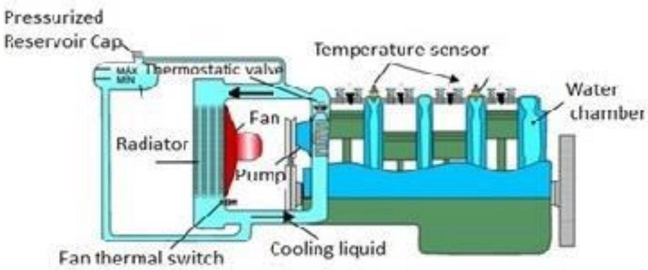

Fig. 3. Cooling system.

According to Thomson [15], coolant is pumped through the engine liners, which are the paths surrounding the hot parts of the engine, such as cylinders, blast chambers, and exhaust outlets. The heated liquid flows from the engine linings through a hose to the radiator where aided by a fan, it cools and returns through another hose to the engine. The coolant thus circulates under pressure throughout the cooling system. The water pump drives this circulation, accelerating the passage of the liquid through an impeller. While the engine does not reach its optimum operating temperature, the coolant circulates only through a small circuit through the engine compartments, which is controlled by the thermostatic valve.

When the optimal temperature is reached (85–95 °C), this valve opens, and coolant begins to flow through the complete circuit. This circuit passes through the radiator, where the outside air and the air stream generated by the ventilator lower the temperature of the coolant. Because it helps to control the engine temperature, the thermostatic valve is an important part of the vehicle's cooling system (Figure 3). When the engine is cold, the valve passage is closed, causing the coolant (water and additive) to return to the engine block. At a certain temperature, depending on the vehicle, this passage opens to allow the passage of the liquid to the radiator so that it is cooled and returns at a lower temperature for the engine block.

The thermostatic valve is a ceramic element and its behaviour is proportional to the temperature of the fluid, it functions passively. The ceramic expands (at temperatures above 30 °C) by moving the piston until it reaches maximum displacement (60°C). At this point, the valve allows maximum fluid transfer to the radiator. As the temperature decreases, the ceramic returns to its initial state, decreasing the flow to the radiator [15]. Other valve models have been developed, with an emphasis on designs with pitch motors (butterfly valve body) and membranes.

In its automotive segment, the company Melling do Brazil has patented a concept for a TCV (patent number US8474419 B2) that uses the membrane concept (Figure 4). Its operation is based on pressure control in the upper chamber of the membrane. As with other models, the outflow is proportional to the amount of fluid supplied by the water pump and is controlled by a solenoid valve located at the top. There is a small passage connecting the inlet to the upper chamber and another passage connecting the chamber to the valve outlet. To prevent the passage of the fluid, the solenoid is actuated by closing the small alternative passage from the upper chamber to the outlet. In this way, the chamber pressure increases, pushing the membrane down. To start the fluid flow, the solenoid is switched off, thus relieving the pressure in the upper chamber.

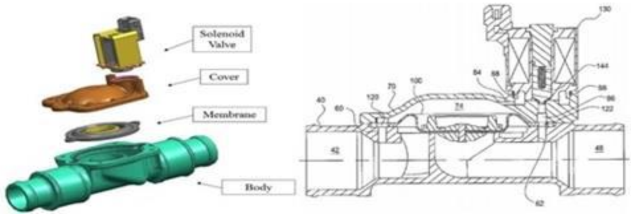

Fig. 4. Temperature control valve with the membrane.

III. APPLICATION OF HALL EFFECT SENSOR IN THE TEMPERATURE CONTROL VALVE (TCV)

Figure 5 shows the application of the Hall Effect sensor for monitoring the position of the membrane with the use of a TCV with position feedback. The Hall Effect sensor is positioned parallel to the membrane with a magnet, thus enabling measurement of the magnetic field of the magnet. This configuration allows the sensor to detect the magnetic-field strength of the magnet via a transfer curve to determine the actual position of the membrane.

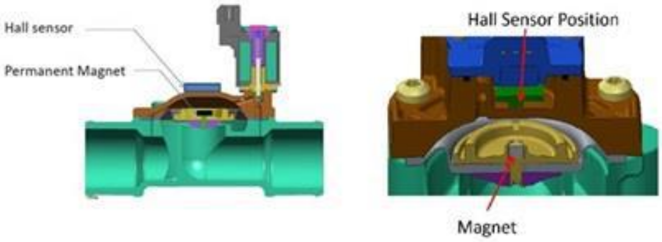

Fig. 5. Temperature control valve with position feedback.

The control system measures the output of the Hall Effect sensor and calculates the position of the membrane according to the function. With this value, the error can be calculated for setting the best duty cycle for the solenoid. This solenoid operates at a fixed frequency of 10 Hz and the control system adjusts the duty cycle based on the error calculation. The adjustment speed is a software parameter that increases or decreases the duty cycle (0 ↔ 100%) as a function of time.

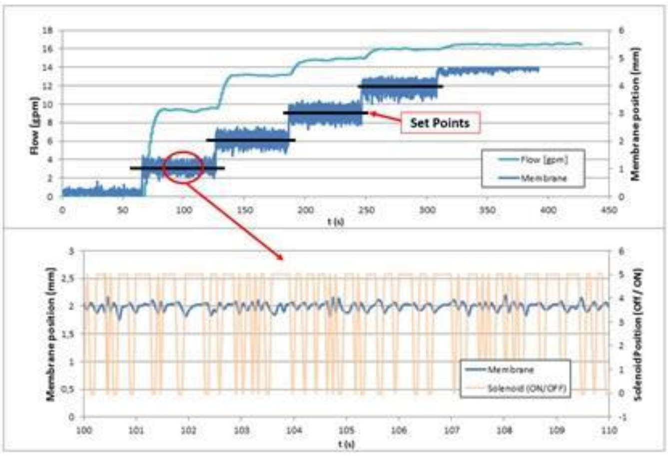

Fig. 6. Flow control and membrane position.

In practice, the control can position the membrane infinite positions, and this positioning will restrict the flow of the fluid passing through the valve. As shown in Figure 6 for a case in which the motor has a fixed speed and thus a constant flow, which we refer to here as maximum flow, the control of the membrane position restricts this flow to intermediate values. In the same Figure 6, we can verify the activation of the solenoid to keep track of the membrane position.

IV. CONCLUSION

The implementation of the Hall Effect sensor in the TCV provides new functionality to temperature control in the internal combustion engine, which has previously operated in just two states (ON and OFF). This advance enhances the precision of the temperature control of the combustion engine, such that its operation now features a multitude of intermediate stages between the open and closed positions, based on feedback regarding the position of the membrane in the valve control circuit. In our experiments, the Hall Effect sensor performed with 100% efficiency in detecting the magnetic field of the magnet attached to the membrane.

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