Utilization of Shape Memory Alloy (SMA) for Temperature Detection and Warning in an Automobile Engine

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Abstract. In the present work a new design of coolant temperature sensor (CTS) was carried out based on intelligent material. This material called shape memory alloy (SMA) which contain Nickel-Titanium alloy that have the ability to contract at different rates of temperatures when utilize in fabrication the spring coil. CTS was designed from SMA this material due to the characteristic of these materials such as the high resistance of corrosion and conductivity of electrical when compared with a conventional sensor. The novel SMA sensor was evaluated according to its performance by changing the temperatures during the period exposure of experiment that has been conducted to test the SMA spring coil. The design of the intelligent system proposed has been the ability to provide more automated control by using advanced materials to reduce each cost and maintenance. Coolant temperature sensor gained the best consequence of performance by getting contraction about 20mm when the range of temperature increase from (85°C – 95°C).

Keywords: Sensors design, Coolant temperature sensor, Shape memory alloy, Application of SMA spring.

1. Introduction
The new technologies or innovation in the automotive industry are constantly getting public awareness. The key concerns are safety, quality, and simplicity when introducing a future automobile. Shape memory alloy (SMA) being one of the well-known smart material has achieved a great interest in developing linear and rotary actuator applications [1]. The main unique characteristics of SMA are offering high mechanical performance, high reversible strain, and large power to weight ratio. By being able to return for their original form when the temperature is increased, SMAs are a distinct type of shape-memory material. In shape reconstruction, even with a high applied load, an increase in temperature can occur, resulting in large densities of actuation power. In addition, under definite conditions, SMAs can be consumed and dissipated the mechanical energy when subjected to the use of cyclic mechanical loading by reversible undergoing a hysteretic form transition. All the actuation, sensing, damping vibration, and impact absorption are SMA applications that have made it more common and are special in characteristics. [2]. Moreover, a better actuation of a property based on
(SMA) Flexinol in along the line of deformation when compared with Nitinol and other SMA materials [3]. Hence, the SMA actuator has provided simple and compact solutions compare to traditional automotive technology.

Recently, Ameduri et. al [4] has introduced SMA wires into the automobile door seal cavity to act as acoustic insulation when SMA wires actuated experimentally and numerical modeling. Another experiment work by Chillara et al. [5] was focused on integrating SMA wires with spring latches to quickly actuate the fender skirt to improve aerodynamic performance. Thus, the SMA wire actuator has shown extraordinary potential ranging from modeling to implementation aspects in automobile application. Shape memory alloy (SMA) has become an advanced material in the intelligent development sciences because of the ability to detect various temperatures (increasing or decreasing) in the engine of a vehicle. In the last few years, many researchers studied SMA where it was a relatively new material that has wide applications in mechanical, biomedical sectors, and aerospace [6]. Within thermal, mechanical, electrical, and chemical problems exhibit SMAs strange thermochemical and thermoelectrically behaviors. For example, Ni-Ti SMAs, Cu-based SMAs, shape memory ceramics, ferrous SMAs, and shape memory polymers [7]. In particular, Ni-Ti SMAs have specific thermomechanical behaviors, such as the shape memory effect. Besides, the pseudoelasticity function makes them attractive candidates for applications during structural vibration regulation. Many studies have been performed to model Ni-Ti SMAs in the application of structural vibration control. Many studies have been performed to model Ni-Ti SMAs in the application of structural vibration control [8].

The Temperature Sensor for Coolant (CTS) is a critical device. CTSs are widely used in automobiles. The main function represents by sending alerts to the control unit which explains that the engine of the automobile is overheating and there some reason occurs in the system should check it. The thermistor is basically the concept of controlling the coolant temperature sensor. The amount of resistance to the thermostat is completely influenced by the increase in temperature. As the temperature increases, the coolant power of the car decreases, which reduces the potential for performance reductions and variations in a turn. This voltage substance will also be sent to the car's Engine Control Unit (ECU), which periodically maintains the increase in resistance that has occurred in the coolant of the car [9]. Also, the Powertrain Control Module (PCM) is told by the coolant temperature sensor about the temperature of the coolant inside the engine. For the PCM, this data is of vital importance because many control functions vary with temperature. If the coolant sensor is defective or reads poor, as it stays in an open loop, it may get rid of the control system, which is a temporary operating mode that should occur only after cooling. Therefore, a defective coolant sensor will cause the engine to run richer than normal, increasing fuel consumption and more gas emissions. [10].

Sensors have been used in a wide variety of applications due to simple equipment integration, such as consumer electronics, automotive, process industries, etc. In addition, in automotive applications such as cylinder head temperatures, coolant, and air intake, temperature sensors have been increasingly used. In Heating Ventilation and Air Conditioning (HVAC), environmental control, food processing, medical policies, and implementation of chemical handling, temperature sensors were also used. [11]. In the vehicle, the coolant temperature sensor (CTS), is a critical device that enables the control units to provide a warning when the engine heats up, even if the temperature inside the system rises for some default purpose. This device is based on the theory that the potential temperature difference is dependent on. As the engine temperature increases, the output potential difference of the sensing system also changes, and this can be sensed by the control unit of the engine. Finally, it can be said that a thermistor is a sensor of coolant temperature. [12].

The purpose of this study is to create a new smart sensing device. In order to overcome ECU defections, this sensor was suggested by sending the electrical signal directly to the alert system, activating the cooling system, and thereby reducing the engine temperature.
2. Experimental procedures

The used materials and objects for the experimental work was Nitinol wire of SMA with a 0.5 mm diameter and 140 mm length. The SMA wire was manually reshaped to form a seven-pitch, 40 mm long spring, as shown in figure 1.

![Figure 1. (SMA) after burned and formation.](image1)

Normal coil spring length of 60.5 mm as explained in figure 2. As can be seen in figure 3, the PVC pipes with dimensions of 16 mm internal diameter, 20 mm external diameter, and 80 mm length were prepared. In this experiment, PVC material was used to withstand and work at a high temperature. In terms of the inner and outer diameter, PVC pipes were selected for the housing within the necessary dimensions.

![Figure 2. drawing for normal pushing spring.](image2)

![Figure 3. Drawing of the operating shaft of PVC pipe.](image3)

As shown in figure 4, the sliding ring was produced using copper. A copper slide ring with an outer dimension of 25 mm, an inner dimension of 21 and a width of 5 mm; and connecting pin with an outer dimension of 1 mm and a length of 25 mm drawn in figure 4. The main function of this part is for the sensor to be switched on and off by initiating electrical contact between the SMA spring and the main screw installed in the engine body.
Nickel-titanium SMAs chosen as the CTS material for prototype manufacturing. The activity of the contraction of SMA with rising temperatures was observed against time. As shown in figure 5, the experiment was replicated five have been times with increasing rates of different temperatures to observe the reliability of the SMA.

In a hot water bath, the developed prototype was submerged. The temperature was calculated by a thermostat connected to the computer lab and registered. The rate of temperature rise was controlled manually by the burner valve. The data was accurately collected through a fixed camera to track the actions of SMA contraction during growing rates of temperature. The high-contraction output occurred by gradually raising the device temperature, resulting in displacement in the slider ring motion and activation of the switch in figure 5. Using varying temperature concentrations, the experiment was repeated five times.

The SMA wire has been shaped into a helical spring, and figure 6 shows the overall assembly collection of the SMA sensor. The prototype has been developed and simulated using "CATIA 5" software. In order to solve ECU defections, a new smart sensing system was proposed by sending the electrical signal directly to the alert system, activating the cooling system, and subsequently decreasing the engine temperature, as shown in figures 7 and 8.
Figure 6. Final configuration of the coolant temperature sensor modules using the SMAs system.

Figure 7. Smart coolant temperature sensor system circuit with a closed-looped loop.

Figure 8. Smart coolant temperature sensor system with an open loop.
3. Results and Discussion
The obtained result reflects the sum of contraction in SMA (mm) and the steady rise in temperature over time. Visual observation and calculation of the contraction and change in temperature were carried out. In a Pyrex glass jar, the deformed SMA spring was measured to make it easier to track. The SMA wire contraction versus temperature is shown in figure 9. At a temperature range of between 85 to 95°C, nonlinear behavior was observed. It has been found that the contraction duration was up to 19 mm. By training this spring to enable at the appropriate temperature (region field of SMA motivation), the design of the SMA application can be versatile. More automatic control, the use of advanced materials, and decreased maintenance and costs can be supported by the proposed smart system design.

![Figure 9. SMA contraction versus temperature tests.](image)

The contraction of the SMA wire due to five different temperature increasing rates was shown in figure 9. For all tests, the length was 10 minutes with a 2-minute time difference. For all experiment sets, the initial temperature of the water bath was 55 °C and showed a rise to 95 °C. An exponential curve in the contraction rate increase was found in the first, second, and third sets of the experiment. In addition to that, we would like to point out the friction happens between slide ring contact and operating shaft concerning the stick of insert pin of the sliding ring, this problem contributed to the cause of any different and abnormal results. The contraction rate does, however, have a logarithmic shift in the fourth and fifth experiments.

Whereas mentioned in previous tests the changing time between each experiment around two minutes, where the total time now is ten minutes. It is possible to consider the behavior starts to be a bit critical due to some defects in the manufacturing technique. Finally, the goal was achieved for both values as 20mm contraction and temperature 85 -95 °C respectively.
Figure 9. illustrates the similarity of conclusions with the third experiment. However, several differences have been noticed: first of all, the range of the moment was constant appeared at the beginning that was in the middle (45 -55°C) of heating temperature, moreover (85-95 °C) in the maximum temperature too. This is possible because the friction was very little when compared to the manufacturing technique. Secondly, the maximum reading of contraction was 18mm - 20 mm at temperature (80-95) °C. In conclusion, 20 mm of SMA contraction was obtained as the best contraction amount because all set of different temperature increasing rate reached the same contraction at the temperature. Thus, this indicates that the SMA system which acts as a temperature coolant sensor in the automotive industry will not affect by different temperatures increasing rate. Furthermore, the extent of 20mm displacement by the SMA is expected to perform a high pulling force as a smart coolant temperature sensor.

The tested SMA spring has a high rate of contraction, resulting in high regulation of the ordinary mechanism spring. As a consequence, at several high-temperature settings, it can be reformed to the initial shape. The CTS system is not affected by the temperature rise rate, which can be considered a benefit for the proposed design. Compared to the ordinary CTS system, the new design has several advantages, which can be summarized as high efficiency, corrosion resistance, applicability, low production costs, and low maintenance requirements. To increase the CTS performance, the CTS thermostat was replaced with the reformed SMA spring and connected with an ordinary spring. A rise in temperature of the SMA spring demonstrated contraction activity from 65 mm to 45 mm.

4. Conclusions
The literature review showed that their contribution to the use of mechanical engineering has been shown to smart materials and some research has been done in this area. SMA wire can modify some of the material characteristics, such as “Young's module,” various powers, damping, high corrosion resistance ability, and greater strength. This study is a new concept to incorporate and apply the outstanding function of SMA wire as a coolant temperature sensor control mechanism in vehicles. In many engineering fields and applications, SMA has been increasingly used, such as’ conjugation and shape control, actuators, composites, shock absorption, vibration damping, biomedical areas, and automatic on-off turn. A smart coolant temperature sensor based on SMA spring was experimentally designed and simulated in this study. It is concluded that the integration of SMA spring as a control mechanism for a coolant temperature sensor in vehicles can improve the conventional mechanism. The experiment results revealed that SMA spring performed a high contraction rate at a variety of high-temperature and temperature increasing rate conditions. It is further highlighted that the smart system design improves sensor performance, corrosion resistance, applicability, low manufacturing cost, low maintenance requirement. Hence, the proposed design of SMA spring as CTS in this research is practically be implemented.

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