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RESEARCH ARTICLE

Protecting car engines and controlling their temperature by using shape memory alloy as an automatic mechanical cooling sensor

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ABSTRACT - Shape memory alloys (SMA) are smart materials with a dual function as a sensor as well as an actuator that can generate cyclic contraction and extension when exposed to an increasing and decreasing temperature. In this work, the potential of SMA in the form of spring as an actuator that activates a warning system for detecting high temperatures in vehicle engine is investigated. The working principle of SMA spring is it activates thermomechanically to generate linear reciprocating motion as a result of the contraction (heated) and extension (cooled). This unique feature is employed in the design of a new type of smart automatic switch that regulates and controls the temperature of the vehicle engine instead of using conventional sensors such as thermocouple. The smart automatic switch has two poles positive and negative, where the positive pole represents the SMA spring, which is completely immersed in the water of the engine. While the negative pole is the operating shaft that collects all the parts of the smart switch and is installed on the engine body. A lab scale experiment was conducted to analyse the displacements and results shown that contraction of 20 mm can be produced from the SMA spring due to pulling force when the temperature of the engine increases from 50 °C to 80 °C and the recovery of the SMA spring to the original position can be obtained by the pushing force 0.5 N from a bias spring when the temperature decreased. From this experiment, a design of the smart switch is that can be utilized the shape memory function is presented. The simplified design proposed demonstrates the shape memory alloy as having good potential in automotive applications such as this as it low cost, space saving, silent operation, and simple in design aspect.

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1.0 INTRODUCTION

Modern technology in the automotive industry is considered the most popular because of the high financial income and the wide demand by researchers in this field. Where controlling and regulating the temperature of the engines for vehicles is considered one of the important things in the safety and extending the life of its performance [1, 2]. One of the most common defects in the engine's Coolant Temperature Sensor (CTS) is that it consists of a thermocouple that sends an incorrect electrical reading to the Engine Control Unit (ECU) because of exposure to continuous corrosion in the sensing part from the water as in Figure 1.

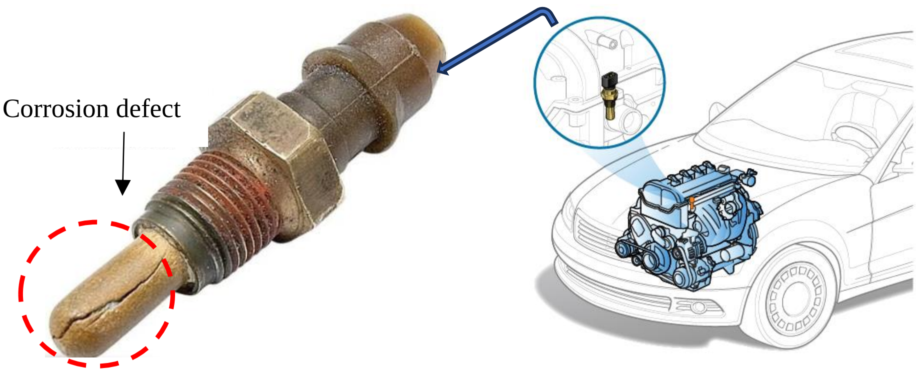

Figure 1. The main defect of CTS in the vehicle engine

The CTS plays a crucial role in monitoring the engine cool and optimal performance of the temperature vehicle. The main function is represented by sending alerts to the ECU which explains that the engine of the automobile is overheating and there is some reason occurs in the system should check it. The increased temperature reduces the performance and variations in the engine such as running richer than normal, increasing fuel consumption, and more gas emissions. In addition, the electrical problems that occur in ECU lead to burning and damage it due to the wrong signal.

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Smart actuators achieve the need for lightweight and small sizes [3, 4]. The shape memory alloy (SMA) is a smart alloy that has unique properties when it activates in a water bath such as high output work and silence in operation for the other conventional actuators. The reason for this activity generated in SMA is the change in the molecular arrangement of the crystal structure resulting from the increase and decrease in temperature as in Figure 2 [5, 6]. Martensite and austenite are two important phases in the transformation temperature of SMA, where austenite represents the active phase when the temperature is high and it is the phase of producing force and displacement, while martensite is the passive phase when the temperature is lower where it is soft and more capable of deformation [7, 8].

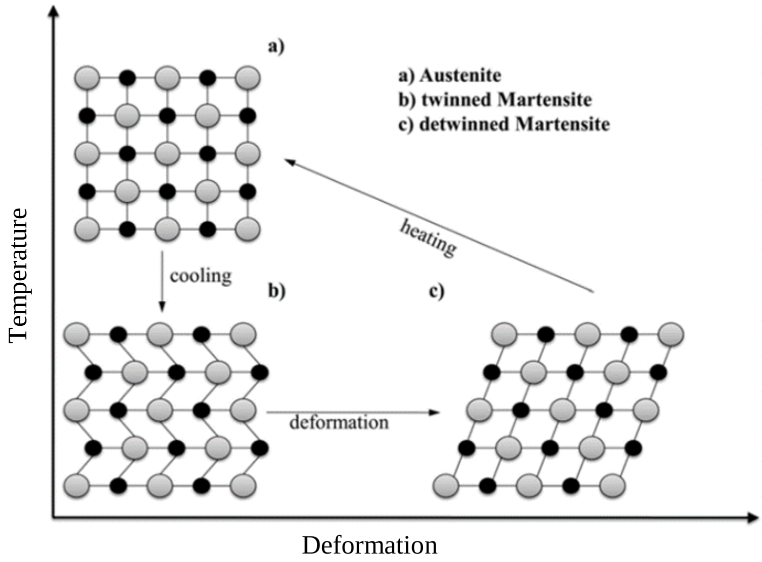

Figure 2. Transformation phase of shape memory alloy

2.0 SHAPE MEMORY ALLOY EFFECTS

Shape memory effect (SME) is the thermomechanical transformation phase of the SMA structure based on the load or stress applied to it that categorized into two types:

1) The one-way shape memory effect represents the ability of SMA to recover the original shape in the Austenitic phase that has been deformed in the Martensitic phase by the application of an external force as in Figure 3 [9, 10].

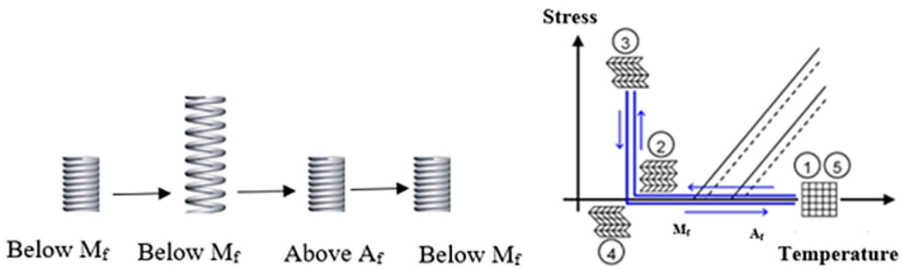

Figure 3. One-way shape memory alloy effect

2) The two-way memory effect represents a less common SMA actuator because of the recovery deformation in the Austenitic phase conducted without external load. It's vital to note that two-way SME offers a very limited of strains and cannot be employed in the majority of applications as in Figure 4 [11–13].

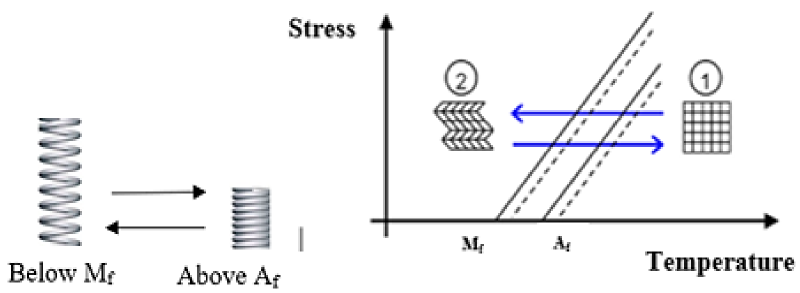

Figure 4. Two-way shape memory effect

Based on the characteristics of SMAs described in the previous section, the performance of SMAs as an actuator can be demonstrated by submerging it in heater water, gradually raising of the temperature at different times of heating, and then cooling it to observe and comprehend the displacement of the SMA contraction produced due to compressing force to the normal spring.

3.0 APPLICATION OF SHAPE MEMORY ALLOY

Numerous commercial products have been created that utilize the characteristics of SMAs since the SME in SMA was found. SMAs are employed in many different applications, including housing, electrical and home appliances, and automobiles. SMAs are used in almost all of these products as springs due to their larger stroke than wire as in Tables 1 [14 –16].

Table 1. The shape of SMA and application

Application of SMA	SMA shape
Automatic transmission valve	Spring coil
Automatic Shinkansen oil valve	Spring coil
Automatic dehumidifiers	Spring coil
Louver of air conditioner	Spring coil
Coffee maker	Spring coil
Rice cooker	Spring coil
Anti-scald valve	Spring coil
Water purifier	Spring coil
Thermostatic mixing valve	Spring coil
Bathtub adapter for adding water	Spring coil
Underfloor ventilating hole	Spring coil
Camera	Wire
Miniature robot	Wire
Rock splitter	Rod
Easy-release screws by SMA washer	Washer

The SMA cannot produce a large force or a large displacement of contraction at the same time depending on the shape of the SMA and the function of design required. The SMA spring produces higher contraction displacement but a small force whereas in contrary of the wire that generates small contraction and high force as in Table 2.

Table 2. Spring and wire of SMA details

SMA shape	Displacement contraction (mm)	Force (N)
Spring coil	60.3	Less than wire
Wire	0.3	Higher than spring coil

The comparison to the one dimension of the SMA wire diameter equals 1 mm but in different free lengths due to shape. The free length to the first shape of the SMA as the straight wire is equal to 30 mm while the number of turns and outside diameter to the second shape of the SMA as spring are equal to 30 and 8 mm respectively as in Figure 5 [12, 17-20].

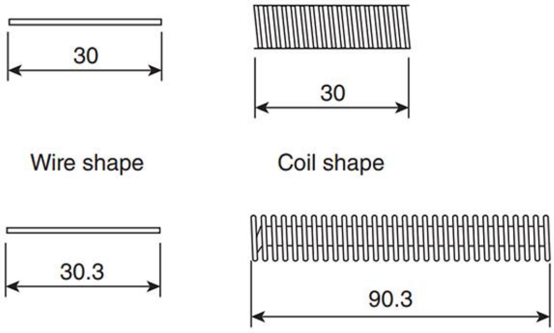

Figure 5. Comparison of displacement between wire and spring of SMA

A consequence to the homogeneous distribution temperature of the SMA spring by immersion in the hot and cold water led to producing a maximum displacement of contraction and fast response in changing temperature and detecting it. The replacement of the thermocouple type of the CTS by the new design of the smart switch for the automatic cooling to detect the increasing and decreasing temperature is the main target of this study to increase the operation safety of the automobile engine.

4.0 EXPERIMENTAL SETUP AND PROCEDURE

In this research, the linear reciprocating motion generated from the thermal activity of the SMA spring was employed to implement the proposed smart automatic switch. In the smart automatic switch sensor, the dual SMA springs are settled with a normal spring in parallel by operating pipe from PVC material. The Flexinol sensor type SMA wire was shaped from wire diameter of 0.29 mm and 140 mm in length to produce a double SMA spring dimension that outside diameter of 5.5 mm, 7 turns, and 40 mm free length. While the outside diameter to the normal spring is 15.5 mm, 17 turns, and 60.5 mm free length with 0.5 mm wire diameter. A bias spring was pre-stressed by the dual SMA spring by 0.5 N and coupled in the water bath. Manually adjustable stove to regulate the increasing and decreasing of temperature. The temperature of the water path was measured by K type thermocouple connected with a LabVIEW software of computer by DAQ. The pointer has two ends, the first end is installed on the sliding ring of the PVC pipe while the second end measures the displacement of SMA spring contraction in the ruler located outside of the water bath. A polymer of vinyl chloride (PVC) is a type of electrical insulation material used especially as pipes and films. The camera was fixed to monitor the pointer with a ruler. The camera, ruler, and springs hang by three clamps to the supporting stand. Figure 6 illustrates the whole system of the smart automatic switch. The material properties SMA spring sensor used in the experiment that summarized in Table 3.

Table 3. Properties of SMA spring [20]

Names	Symbols	Units	Values Martensite	Austenite
Young's modulus	E	GPa	30	80
Density	$\boldsymbol{\rho_D}$	g/m^3	6.45	
Specific heat capacity	c	J/g K	0.2	
Thermal conductivity	k	W/cm * °C	0.18	8
Latent heat of transformation	ΔH	Cal/g	5.78	

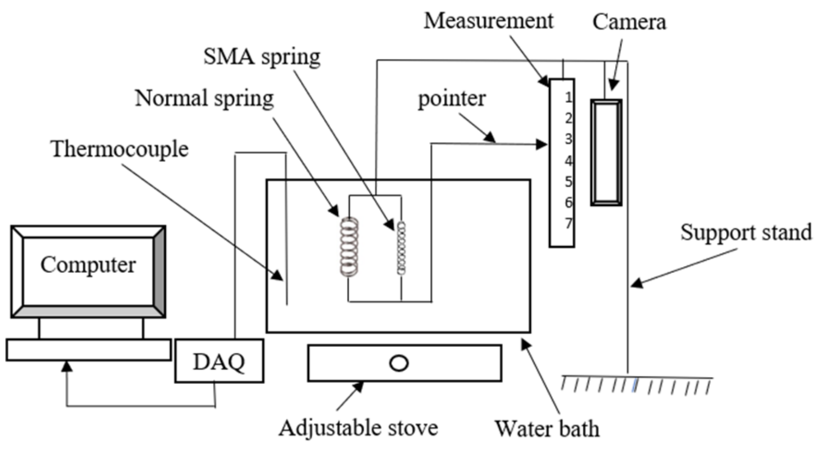

Figure 6. SMA spring experimental setup

5.0 RESULTS AND DISCUSSION

The experiment was conducted via increasing the temperature of water when applied prestress to the SMA spring by the normal spring. Figure 7 explained the technique of increasing temperature by heating water from 30 ℃ to 80 ℃ and then cooled down from 80 ℃ to 30 ℃. The response of the SMA spring to increasing temperature was regular and slow based on the slope of temperature versus time whereas the response in the cooling or passive phase was faster where the slope was very small. This step was performed by using an adjustable stove underwater container to control the period of increasing temperature while decreasing temperature implemented by adding cold water.

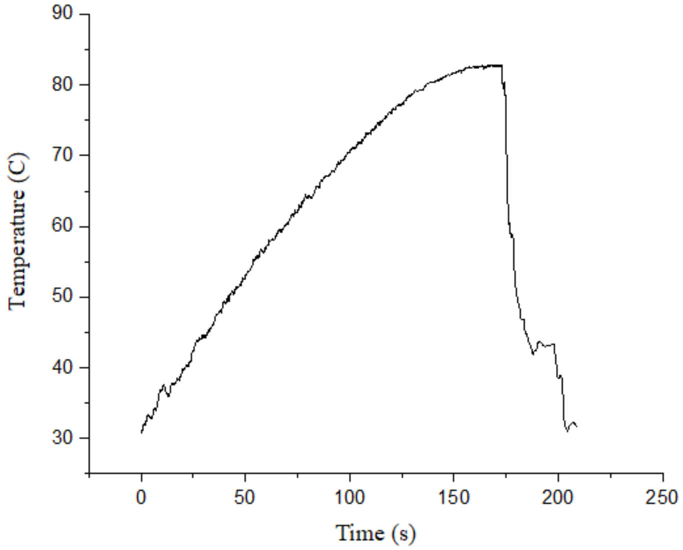

Figure 7. The relation between increasing and decreasing temperature against time

Followed by measuring the thermomechanical performance in different periods of heating water. The SMA spring was activated by increasing the temperature of the water bath even fully contracted five times with two two-minute difference between each one. This step was controlled manually which was adjustable by the grade on the burner valve. This step of the experiment showed the responses of the SMA spring depended on how fast of increasing temperature as in Figure 8. The test five was faster in contraction and more regular in motion displacement 20 mm without any stuck in contraction in opposite to the fourth first tests.

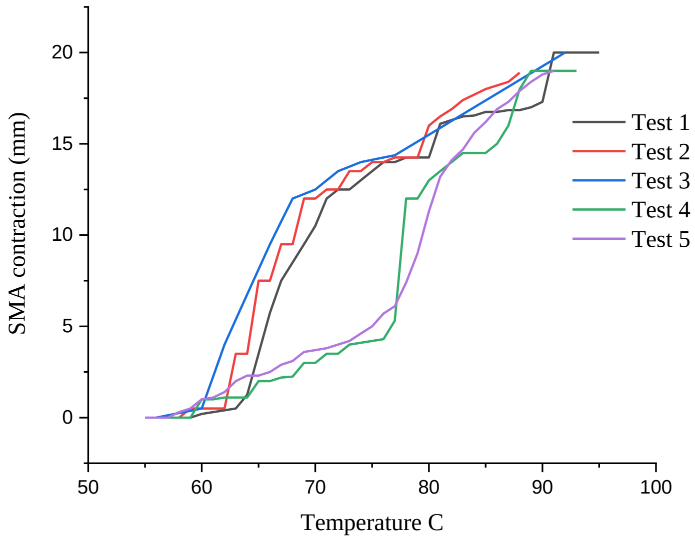

Figure 8. Contraction versus temperature in the heating phase of the smart automatic switch

Based on the experimental results that have been achieved in the SMA spring and its unique properties such as pulling force produced from the thermal contraction. The thermodynamic cooling sensor has been designed because it depends on the high-ability SMA spring to sense the temperature of the engine coolant water in automobiles and the high response when the temperature of the water changes. The thermodynamic cooling sensor represents a smart automatic cooling switch that considers the alternative of the cooling temperature sensor (CTS) due to high corrosion resistance as in Figure 9. Since the function of the smart automatic cooling sensor as a switch led to the manufacture and design of the parts of the sensor in a different material to avoid the short circuit throughout the performance as illustrated in Table 4.

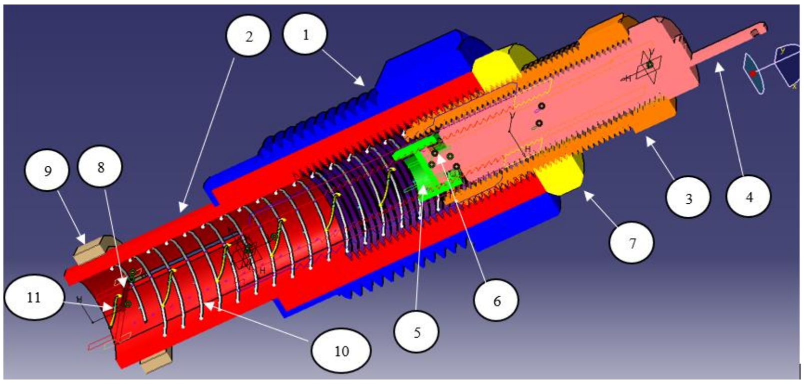

Figure 9. Section view to the parts assembly of the smart switch for the automatic cooling

Table 4. Materials of parts for the smart automatic cooling switch

Name of part	Number of parts	Quantity	Material of part
Main screw	1	1	Cupper
Operating shaft	2	1	PVC
Adjusting screw	3	1	PVC
Conduction shaft	4	1	Cupper
Cylinder free rotation	5	1	Cupper
Lock pins	6	2	Cupper
Lock screw	7	1	Cupper
Lock pin	8	1	Cupper
Slipping ring	9	1	Cupper
Normal spring	10	1	Iron
SMA spring	11	2	Shape memory alloy

Based on the validity and effectiveness of the advanced materials in the design of the mechanical sensor, the electrical circuit of this sensor has been designed, which controls and monitors the temperature of water inside the vehicle's engine as in Figure 10. The result of the increase and decrease of water temperature is contraction and extension of the SMA spring that causes the opening and closing of the electrical circuit of the smart automatic switch where the displacement amount as reciprocating linear motion measured by the pointer was 20 cm and the temperature ranges between 70 ℃ - 80 ℃.

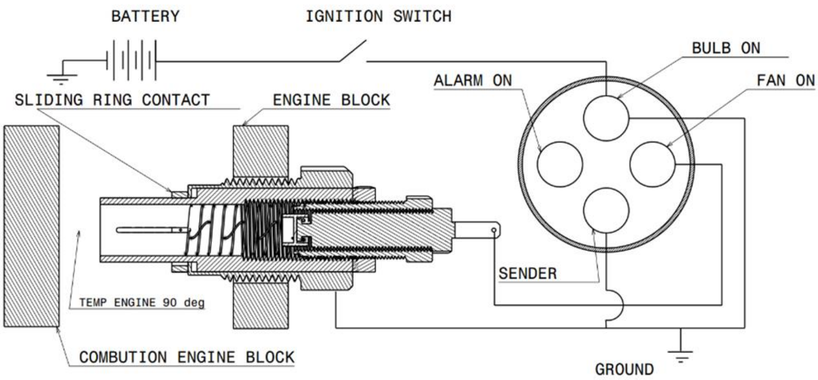

Figure 10. The electrical circuit of the smart automatic cooling sensor

6.0 CONCLUSION

The shape memory alloy occupied a widespread area in the application of sensors and actuators based on the shape and characteristics of the design required. The high efficiency of the performance SMA spring and the speed of response to the transformation temperature when placed in hot water produced linear displacement motion and pulling force. The new design of the smart automatic switch has become an alternative to the coolant temperature sensor consequence of its low maintenance and production cost with high corrosion resistance. An increase in the temperature of the engine water from (70-80) ℃ causes a contraction SMA spring with a displacement of 20mm that leads to an opening of the electrical circuit due to the contact between the electrodes of the smart automatic switch, which results in the operation of the cooling fan, lamp, and alarm on the dashboard of the car.

7.0 ACKNOWLEDGMENT

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