Green Relay Mechanisms Using Shape Memory Alloys

Arbaaz Khan
Manipal Institute of Technology
#490, Jal Vayu Vihar,Kammanahalli,Kalyan Nagar,Bangalore,India-560043
arbaazkhan2@gmail.com

Abstract**—**Green Design Mechanisms are becoming more common as the needs for cheaper and efficient energy management systems are increasing by the day. Due to habits such as overcharging devices or leaving chargers unplugged, a lot of energy is wasted worldwide in the form of heat loss inside the coils of the transformers present in charging stations for devices such as mobiles, televisions, Ipods and laptops. Further several other components such as air conditioners require huge motors and high initial current to control switching of the compressor when ambient temperature falls below preset temperature. Using Shape Memory Alloys a unique relay mechanism can be designed which can control the above said devices, reduce power losses and have a huge impact worldwide on energy savings.

Key Words—Green Design, Transformers, Smart electronics, Shape Memory Alloys, Green Computing.

I. INTRODUCTION

Till date a lot of work using the crystalline properties of shape memory alloys (SMA) has been done in the field of robotics and as a substitute for actuators in aircrafts [1]. Under this paper for the first time the author has tried to use the properties of these materials as a replacement over conventional relay mechanisms in electrical circuits. The advantage of using these materials can be faster response time , lesser power consumption and ease of manufacturing. In large plants where central air conditioning exists, there are motors to control switching of the compressor when ambient temperature falls below preset temperature. Naturally these motors need higher amount of electricity due to their high initial starting torque . In such a scenario it is better to use the proposed mechanism thus saving a huge amount of power.

a. Crystalline Properties of SMA

Shape memory alloys have the unique property of remembering their previous shape. These materials can be deformed to any desired shape but on applying a suitable external stimulus (a change in temperature) the material returns back to its original phase/state. This property is due to the change in crystalline structure of the element at different temperatures [2], [3]. Let us consider the parent phase (also called the austenite state). It is a high temperature high symmetry cubic shape. When it is cooled to a certain temperature say M_s the martensitic transformation takes place and the material gets converted to a low symmetry low temperature shape (It is called as twinned martensite state). This state when loaded with any mechanical stress, easily gets deformed and transition to the deformed martensite state takes place. The deformed material continues to remain in the deformed martensite state until it is heated to a certain temperature (say M_f). Once M_f is reached it returns back to its parent state. When the heat is removed and the parent stage cooled, the material returns back to its low temperature low symmetry twinned martensite state [4]. Thus this repeated cycle can be performed using shape memory alloys with very little loss of mechanical energy arising due to hysteresis [5], [6].

Figure 1: This image shows the transformation of the material from deformed martensitic stage to parent state when immersed in warm water. After the clip is removed from water, its dimensions remain same even though internally it undergoes a transformation from parent to twinned martensite state.

In addition properties of shape memory alloys have been used for various purposes such as pseudo elasticity and pseudo elastic membranes [7]. It is important to note that the transformation from any one phase to the other is independent of time and simply depends on temperature. Once the required temperature is reached the change in phase is instantaneous.

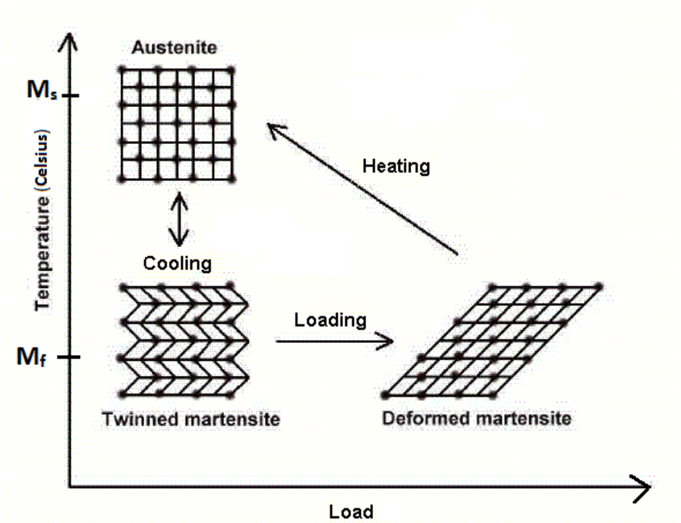

Figure 2 : This diagram demonstrates the different changes in phase of any shape memory alloy as explained above.

b. Existing Solenoid Based Relay Mechanisms

Relays are a general component of every electrical circuit that requires automatic switching. The working principle of a relay is based on Faradays' Laws. When an electric current flows through the coils of the relay, a magnetic field is induced and this exerts a force. This force is then directed to the core of the solenoid thus allowing it to make or break electrical contact with the circuit as and when required. In modern day chargers for platforms such as mobiles, televisions and phones, once the load (battery) is done charging, no more current flows through it and thus the secondary coil (shown in figure 4) of the transformer no longer draws current. However the primary coil of the charger continues to draw current and power is wasted in the form of heat loss. The authors' main aim is to reduce this current wastage (see conclusion for energy savings). Installing a relay in the primary core of the transformer is a good option to cut off the current in the primary coil but it increases the size and cost of the charging device. Also to install a relay in the primary side of the transformer an additional sensing circuit to detect change in battery voltage level needs to be put in place.

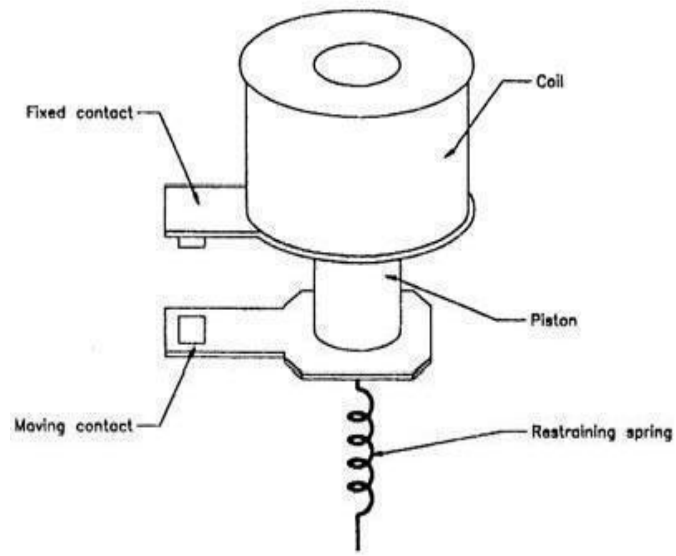

Figure 3 : A general relay mechanism. The piston shown moves down to compress the spring due to the magnetic force exerted by the coil, when an electric current flows through it. The spring sends it back to its original state when the circuit needs to be changed.

Further, more current is wasted in keeping the coils of the relay energized. In addition relay mechanisms have a fixed number of life cycles. Their replacement would be cheap in small scale applications such as mobile chargers, but in the case of central air conditioning, such repetitive repair and replacement can increase the cost of maintenance of the unit. Thus relay mechanisms prove to be redundant if installed inside the primary side of the transformer to save power. Instead of this, the author has tried to use a different mechanism to reduce the continuous wastage of current in the primary coil of transformers and bigger units such as those of air conditioners and other cooling machines (refrigerators also use relay mechanisms to switch the compressor on and off). In skyscrapers or huge buildings where central air conditioning units are used, a lot of power can be saved by cutting off power from the grid when it is not needed. Consider the following diagram (Figure 4) which shows a basic representation of an electric transformer that is widely used in chargers for consumer electronics to step down the voltage of the main supply.

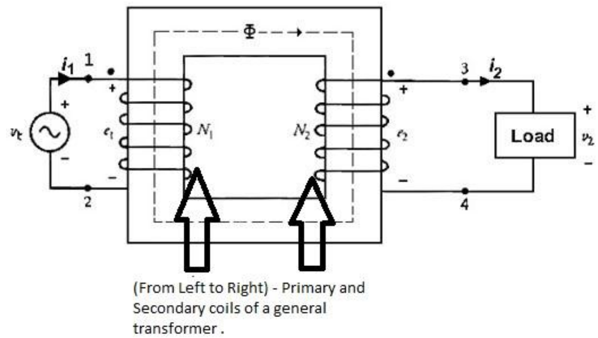

Figure 4 : A general transformer that is present within every consumer electronic device for stepping down the voltage.

II. Experiment

The shape memory alloy and its properties as described in the above section can be used to model our ideal transformer. In addition to heating, shape memory alloys can also be activated electrically [8]. Under the influence of a small current, the shape memory alloy undergoes a phase change and the current required for this is as small as a few hundred milli amperes. The heating is due to the joule effect given by the equation :

$$H = I^2RT \qquad (1)$$

where H=heat produced in joules;
I=current flowing through the wire element;
R=Resistance of wire ;
T=Time taken.

Thus the experiment revolves around the idea of electrically simulating the nitinol wire (a shape memory alloy commonly available) to create an open circuit in the primary loop of the transformer. The power needed for electrical stimulation is drawn from the battery that was being charged. When the battery voltage rises above a certain level, that is once the battery gets charged, the resistor network creates the calculated voltage drop and provides enough current(400 mA) for the nitinol element to change its shape [9], [10]. The following circuit diagram helps demonstrate this experiment :

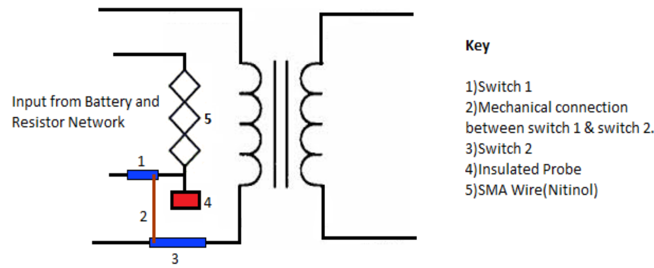

Figure 5 : Experimental Setup for using a SMA as a relay.

In the above setup let us consider the time at which the circuit has charged our battery completely. The SMA shown is deformed (has been compressed) and its original shape (parent/austenite phase) is longer than the one shown in the diagram. Thus due to the above explained properties of SMA, on heating it shall change its shape i.e. expand in length. When this happens it pushes the insulating probe (marked as 4) downwards. The probe pushes Switch 3 and open circuits the primary loop of the transformer. Now to ensure that our charged battery does not discharge through the SMA we have connected another switch, Switch 2 which is mechanically connected to Switch 3. This ensures that when switch 3 opens, automatically switch 2 also gets opened. This prevents the battery discharging through the SMA.

This mechanism works fine as long as our charger is connected to the battery. But in addition to this we need a small mechanism to restore our primary side connection, if we have to charge the battery again. For this we consider the following setup :

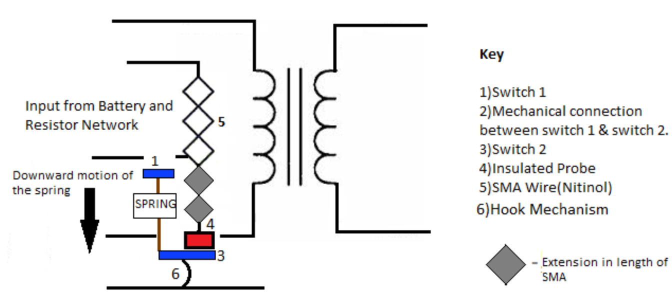

Figure 6 : Representation of the experimental setup to restore SMA to original position.

In this figure the SMA is shown to not make any electrical contact. In addition we have installed a small spring mechanism that ensures whenever the insulating probe deactivates switch 2, it pulls a tiny spring (calculations below) attached to switch 1 thus disconnecting switch 1 too. Simultaneously a hook mechanism is deployed which does not let the spring restore the device until an external switch (which controls the hook) is opened causing the spring to restore the entire SMA and switches 1 & 2 to their original position. This mechanism is similar to a ball point pen. This ensures that the user can use the circuit to charge the battery again. The following parameters were used for the simulation of the device :

1)Resistance of Nitinol Wire : 1.9 ohms/Inch for wire having 0.005 mm diameter of cross section.
2)Weight of Insulating Probe : 25 grams = 0.025 kg
The Nitinol element shows no deformation for the weight of 5 grams under the twinned martensite state.
3)Restoring Constant of the Spring used for the switch :
50 N/m
4)Current Required for stimulation of nitinol wire : 400mA [11].

III. RESULTS AND ANALYSIS

The model for the spring mechanism was generated using CATIA and the analysis for the spring mechanism to open and close the switches using restoring force of the spring was done using Ansys. A daily purpose spring made of hardened steel with a restoring force constant of 50 N/m was used to simulate the restoring mechanism. Further the nitinol wire was tested under laboratory conditions . It was found that though the wire responded quickly to electrical stimulation using D.C current, it resulted in uneven heating of the wire. This can result in the material turning brittle and/or short circuiting the connections. This was observed especially after repetitive use of the element. Thus due to this reason, the author has chosen to use pulse width modulation for activation of the SMA. Previously a lot of work has been done in stimulating shape memory alloys using pulse width modulation current instead of direct current [12],[13]. This ensures that there are no "cold spots" in the heating, and the material retains its properties and does not become brittle after repetitive usage. A simple 555 IC timer has been used in previous research papers (cited here) to produce pulse modulated current. The same circuit was used in this experiment and the schematic is shown below :

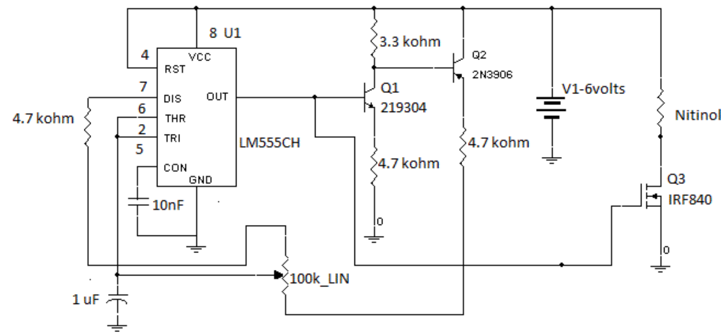

Figure 7 :555 IC timer circuit used for Pulse Width Modulation.

Output of the above circuit that is fed to the nitinol wire :

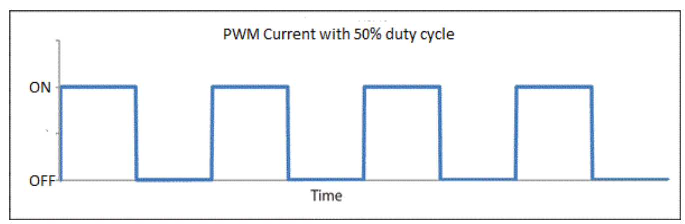

Figure 8 :Pulse width modulated wave generated by 555 with duty cycle of 50% to stimulate the wire.

In addition to this the same pulse width modulated wave can be generated using two op amps where the output of a triangular wave generator is fed to a differentiator circuit. By adjusting resistor values the duty cycle of the output square wave can be varied as shown in Figure 9. The frequency of the pulse width modulated output of the third stage is given as:

$$f = \frac{1(R2)}{4(R3)(R1)C1} \quad (2)$$

An op amp circuit has been shown because can be easily manufactured and are extremely cheap in addition to being very small. In some ways an op-amp circuit would be more useful in any application where you want to slow down the frequency of the current. This gives the user the ability to control the response time of the SMA by varying the on and off time for the pulse width modulated output.

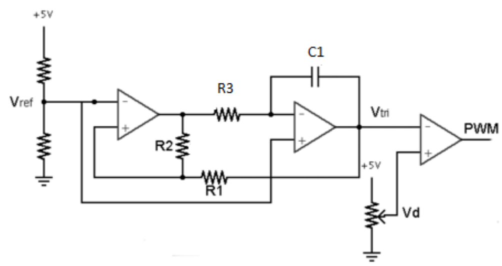

Figure 9 : This circuit gives an alternate method to produce pulse width modulated current for the nitinol wire.

In the above schematics the indicated 6 volt / 5 volt power supply comes from the battery. Also in both the cases the IC does not consume much power as it takes only a few seconds for the current to activate the nitinol element. Rest of the mechanism, involving the switching and restoring via a spring switch remains the same. Thus after using the pulse width modulated circuit (simulated on PSPICE) the nitinol wire responded in a stable manner and hence this concludes the experiment.

IV. CONCLUSION AND DISCUSSION

On an average the number of mobile phone users around the world is in excess of 6,800,000,000 [14]. Assuming the device described above is installed in every charger, its operation time is 1 hour every day (for minimalistic power saving calculation), the cost of 1 watt hour of electricity is 0.10 cents(USD) {The actual cost in other countries is generally higher and most of the times it is a tiered plan} and the average power consumption of a charger during no load condition is 0.20 watts / hour. This calculation gives us a saving of around $500 Million yearly just on mobile chargers!. If the device would be used for as long as we actually keep chargers connected to the mobile phone, the savings would cross the billion dollar mark worldwide. Further if this idea were to be extended to devices such as laptops, IPods' and other electronic devices the savings would be phenomenal, considering the fact that the manufacturing cost for the above device is only around 50 cents. Thus through this paper the author has tried to bring about a novel way to reduce what is called no load power and vampire power in today's consumer electronics. Hence the authors' claims about using SMA as a substitute for relay mechanisms holds good.

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