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Temperature Measurement of NiTinol Spring without Physical Contact

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Abstract: Currently, scientists from various fields are trying to find new ways of activating devices, considering the renewability of the used resources. The way to this goal can also be the search for the usability of various advanced materials in hitherto unexplored areas of technology. This article delves into the application of a non-contact infrared sensor MLX90614 to track dynamic temperature changes in a nitinol spring. By utilizing a controllable external power source, the material's temperature is manipulated through current modulation. This fluctuation is then captured and logged by a system that includes a microcontroller and a temperature sensor. The study's results provide vital information on the correlation between temperature and electrical properties, providing significant insights into the thermal behavior of nitinol springs for future research in this specialized field.

Keywords: nitinol, SMA material, infrared temperature sensor, spring

1. Introduction

The application of materials and their physical properties is fundamental in addressing challenges across various fields. Also, the temperature is very often measured in the industry [1]. In this article, the subject of shape memory alloys (SMAs) was considered, with a particular emphasis on nitinol - one of the most used types. At lower temperatures, nitinol, like many metallic alloys, can undergo plastic deformation [2]. However, unlike conventional alloys, nitinol - a nickel-titanium alloy - possesses a remarkable ability to revert to its original shape through a defined internal temperature shift, known as the shape memory effect. This unique property sets nitinol apart and allows for the restoration of deformation by simply increasing the temperature [3]. The material's ability to exhibit this behavior is rooted in a change in its internal structure (as illustrated in Figure 1), which prompts a transition between the austenite and martensite phases upon a shift in temperature.

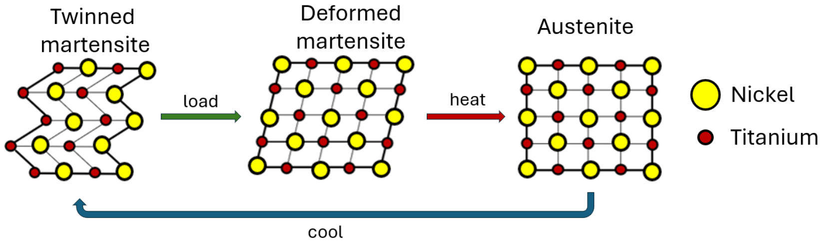

Figure 1: Structure change of the SMA material – NiTinol.

In the process of restoring deformation, shape memory alloys become actuators by converting heat into mechanical energy, thus generating force [4]. Different methods, including heat transfer, radiation, or electric Joule heating, can be utilized to provide

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heat to the actuator [5].

Achieving precise measurements of the heat supplied to nitinol requires a reliable approach. The most efficient method involves using temperature sensors to monitor the surface temperature of the material. To fulfill this requirement, the non-contact infrared sensor MLX90614 will be utilized.

2. Experimental work

As part of our experiment, a spring that is composed of nitinol was utilized. This spring is made from a 150 mm long wire with a thickness of 0.75 mm. Once the spring is heated and enters the austenitic phase, it will contract and reduce in size to a length of 20 mm with a diameter of 7 mm. This type of Shape Memory Alloy (SMA) material can function as an actuator through two distinct mechanisms. The first mechanism is known as one-way SMA, which allows the material to undergo arbitrary deformation (as shown in Figure 2. A). Upon heating, it will revert to its original pre-trained shape – SMA effect (Figure 2. B), and when cooled, it will retain this trained shape (Figure 2. C) [6].

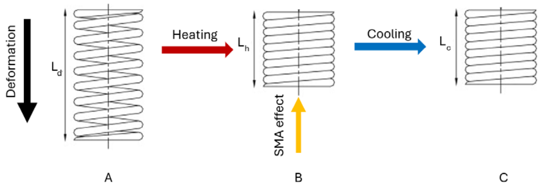


Figure 2: The fundamental functioning of the one-way nitinol spring.

The two-way SMA actuator allows for arbitrary material deformation, much like its one-way counterpart. When heated, the material takes on one of its pre-trained shapes, but upon cooling, it transitions into a second pre-trained state [7]. Our experiment will utilize springs operating as one-way SMAs. By heating the spring, the shortening is induced, while attaching a weight to the end of the spring achieving elongation deformation. The weight exerts a force in the opposite direction to the SMA actuator force during heating.

The temperature will be measured by the infrared non–contact temperature sensor MLX90614. This sensor functions based on the principle of infrared radiation, allowing it to gauge the temperature of objects by detecting electromagnetic waves emitted as light. Equipped with a low-noise amplifier featuring a 17-bit ADC, it enables non-contact temperature assessment. Designed to handle various temperature environments, it operates effectively within a range of -40 °C to 125 °C for ambient temperature and -70 °C to 380 °C for object temperature, maintaining a standard accuracy of ±0.5 °C. This sensor is easily programmable and connectable to the Arduino platform, as the microcontroller itself contains libraries for working with this sensor (Figure 3) [8, 9].

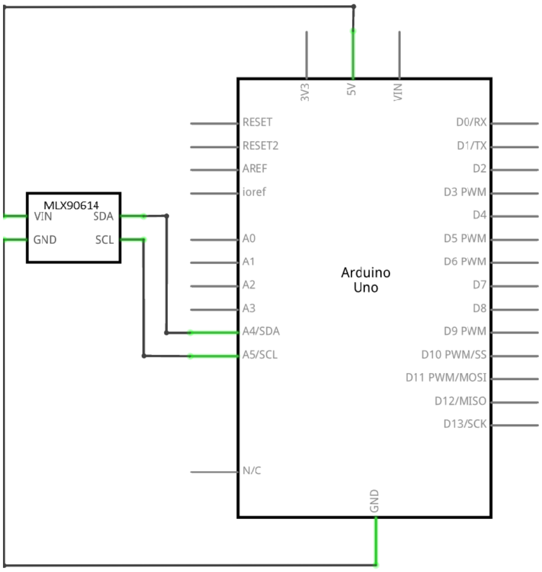


Figure 3: Arduino Uno and the sensor MLX90614 – connection.

3. Verification and testing of the proposed approach

For the upcoming experiment, a workspace (Figure 4) was designed, that includes the following components:

- *Nitinol spring*
- *0.5 kg weight*
- *an infrared temperature sensor MLX90614*
- *Programmable DC power supply*
- *Arduino UNO microcontroller*

To monitor temperature changes in the Nitinol spring during the experiment at a sampling frequency of 2 Hz, the non-contact infrared temperature sensor MLX90614 will be used. It will be affixed to the stand's structure using a bracket and placed behind the Nitinol spring, connected to the Arduino UNO microcontroller. One end of the Nitinol spring will be secured to a bracket on the stand's structure, while the other end will have a 0.5 kg weight attached to it. Both ends of the Nitinol spring will be connected to the programmable power supply, which will administer a constant current starting at 1.4 A per measurement. The current will increase incrementally by 0.2 A until it reaches the limit of 5.2 A.

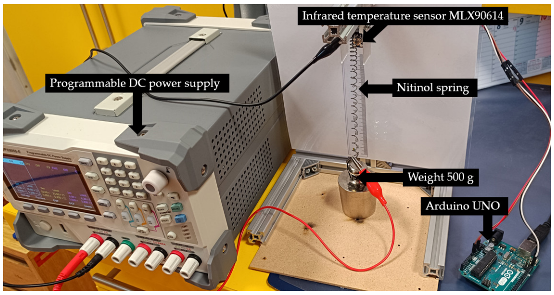


Figure 4: Experimental workplace for testing nitinol spring.

Through experimental determination, the minimum current necessary to produce a sufficient force for lifting the weight was established, which will be utilized in the experiment. The initial stage of the experiment (depicted in Figure 5. A) involves monitoring the temperature increase of the elongated nitinol spring as the weight is raised to a uniform height, representing the maximum extension of the spring (Figure 5. B). This height will be achieved using a programmable power supply, set to a constant current. The subsequent phase will entail observing the cooling of the nitinol spring until the weight, influenced by gravity, descends back to the base, resulting in the deformation of the spring (Figure 5. C).

4. Results

Data collected during our experiment underwent analysis through graphical representation. From these datasets and graphs, the following dependencies could be inferred:

During the initial phase, the nitinol spring demonstrated exponential heating across each current setting. In the subsequent phase, the nitinol spring exhibited linear cooling during deformation induced by the weight (Figure 6).

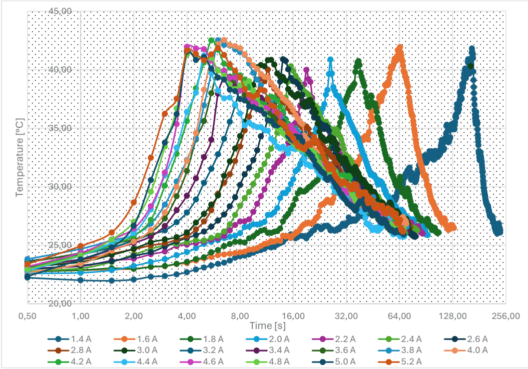


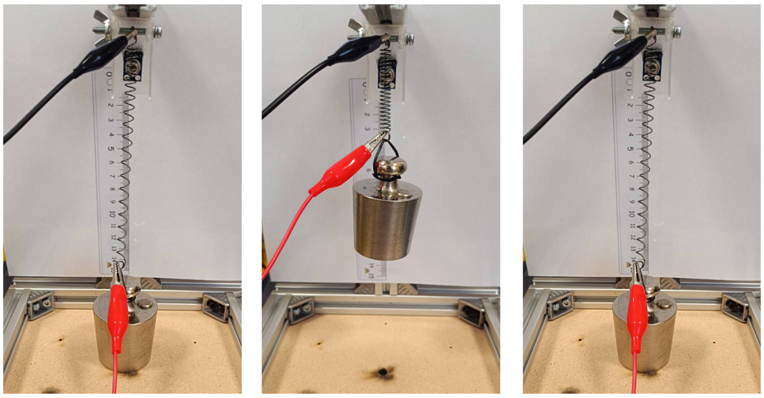
Figure 6: Experimentally gather data – a graph of dependency between electric current, temperature, and time.

At the point of maximum contraction of the nitinol spring and simultaneous lifting of the weight, the temperature stabilizes within the range of 39.11 °C – 42.50 °C, irrespective of the magnitude of the electrical current (Figure 7).

As the current increases, the duration of lifting a 0.5 kg weight decreases (Figure 8). Analyzing the collected data, the relationship between time and electrical current can be characterized as experimentally obtained the power-law function:

$$T = 151.83 * I^{(-1.25)} \quad (1)$$

where: T = time [s]; I = current [A]



A B C

Figure 5: The course of the experiment - steps.

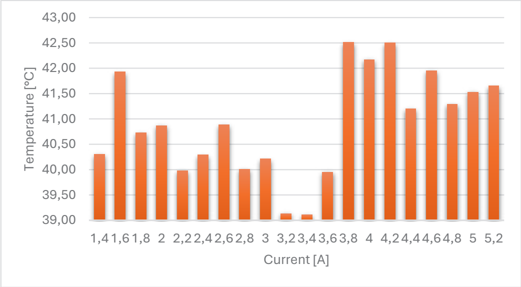


Figure 7: Experimentally gather data - a graph of different temperatures at different current sizes, at the point of greatest shortening of the spring.

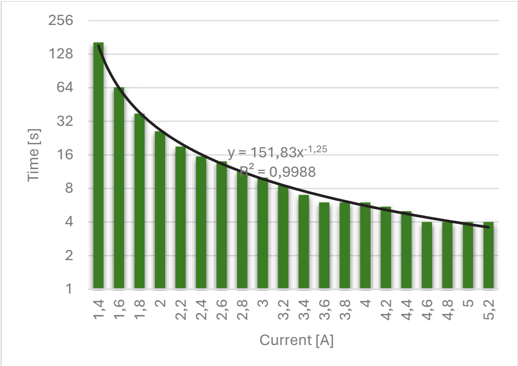


Figure 8: Experimentally gather data - a graph of the dependency between electric current and the time to reach the maximum shortening of the spring.

5. Conclusions

In this article, we explore the temperature assessment of a nitinol spring - a Shape Memory Alloy (SMA) material - using the advanced MLX90614 infrared non-contact temperature sensor. Through our comprehensive measurements and data collection, we discovered that as the electric current rate increases, the time taken for spring shortening decreases, ultimately resulting in the lifting of the load. The knowledge and insights gained from this experiment serve as a solid foundation for future investigations with nitinol springs in our department, which may include measuring the force generated by the SMA material or developing more efficient cooling methods.

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