Individual Analytical Analysis:

Electrical Heating

Capstone Team 4

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Introduction

The goal of this analysis is to answer a few key questions regarding activating the nitinol wire in the Stellar Hold's hold down and release mechanism design. The spring will be activated by heating the nitinol with a current. When activated the spring will expand and provide a specific amount of force to actuate the release subsystem. These questions listed below are needed to move forward with the design:

1. What is the resistance of the Nitinol spring?
2. How much current will be needed to heat the wire to its transformation temperature?

The following is a list of all the variables used in this analysis and their definitions.

Variable Definitions:

- d = diameter of wire (mm)
- D = diameter of spring (mm)
- L_c = length of spring at martensite state (mm)
- L_H = length of spring at Austenite state (mm)
- m = mass (g)
- T_2 = temperature required for Austenite state (^OC)
- T_1 = temperature required for Martensite state (^OC)
- I = current in amperes (A)
- R = resistance in ohms (Ω)
- t = time to actuate (s)
- N = number of coils (#)
- k = Boltzmann constant = 1.380649x10^-23 ($\frac{J}{K}$)
- c = specific heat ($\frac{J}{kg*^OC}$)
- Q = Heat in Joules (J)

Electrical Analysis

During this analysis a few dimensions and specifications will be assumed based off a Nitinol spring that the team has purchased from Nexmetal Corporation [1]. Total time of actuation is assumed to be 0.5 seconds due to General Atomics requirement of "quick" reset. The specific heat of Nitinol was found on a website that listed common Nitinol Properties [2].

Nitinol Spring Specifications/ Assumptions:

- d = 0.7 mm
- D = 9.0 mm
- Lc = 15 mm
- Lh = 45 mm
- m = 1.28 g
- T_2= 60 ^OC
- T_1 = 30 ^OC

- N = 25
- t = 0.5 s
- c = 836.8 ($\frac{J}{kg*^{O}C}$)

To find the required current to heat the wire we must first find an equation that shows the relationship between temperature, current, resistance, and time. This exact relationship is shown in Joule's equation of electrical heating [3], [4]:

$$I = \sqrt{\frac{Q}{R*t}} \quad \text{(Eqn. 1)}$$

Heat (Q) needs to be in terms of Nitinol characteristics and the temperature difference needed. This equation can be seen below. Combining the equation leads to our final equation for finding current [5].

$$Q = m * c * (T_2 - T_1) \quad \text{(Eqn. 2)}$$

$$I = \sqrt{\frac{m*c*(T_2-T_1)}{R*t}} \quad \text{(Eqn. 3)}$$

The only variable missing to solve for current is the resistance (R) of the Nitinol spring. Figure 1 shows a graph of the electrical resistivity of Nitinol vs temperature. Assuming a starting temperature of 30 ^{O}C (303.15 K) we can see that the resistivity of the Nitinol will initially be around 5*10^{-5} Ω*m. For the heated state it raises to 333.15 K with a resistivity of 80*10^{-5} Ω*m [1], [6].

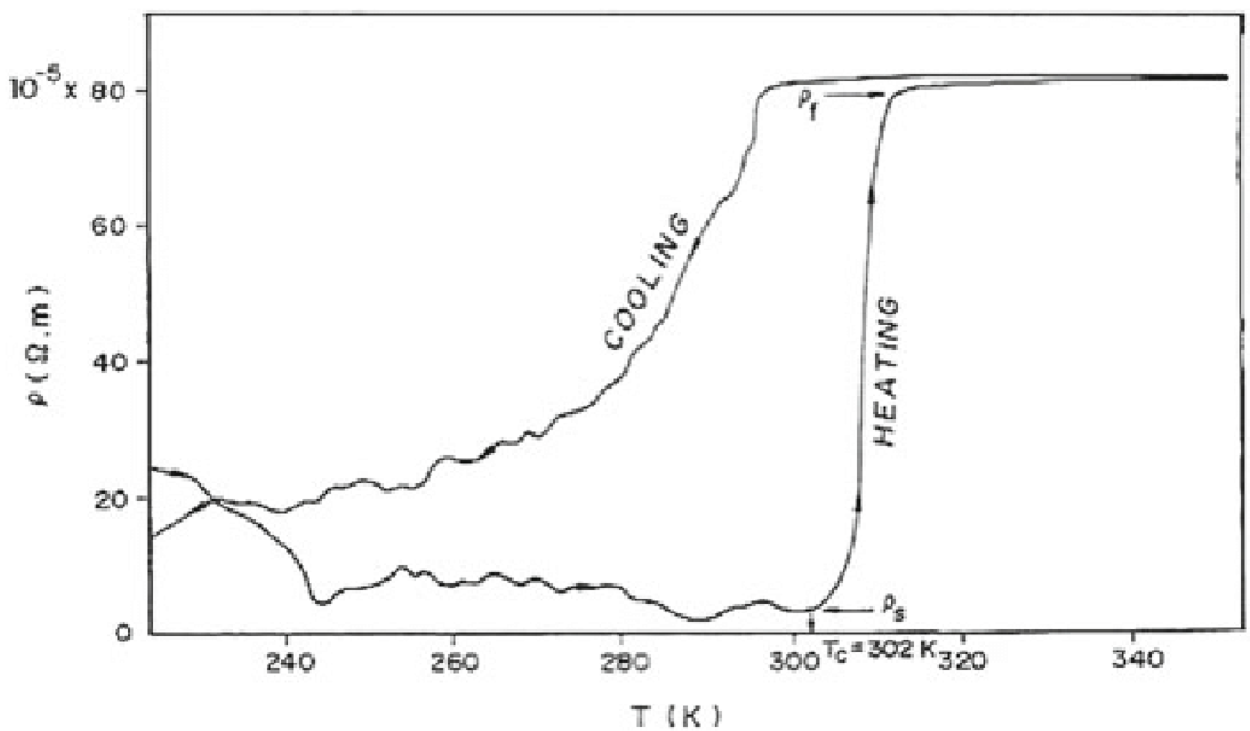

Figure 1: Nitinol Resistivity vs. Temperature [6]

Combining equations 4, 5, and 6 will result in the formula of resistivity of the Nitinol spring in terms of the area of a circle and length of a spring (Eqn. 7). Equation 5 is the area of a circle and equation 6 will give the length of the coiled spring. The final equation (Eqn. 8) solves for the resistance of the Nitinol spring [7], [8].

$$\rho = \frac{R*A}{L} \quad \text{(Eqn. 4)}$$

$$A = \pi * r^2 \quad \text{(Eqn. 5)}$$

$$L = D * \pi * N \quad \text{(Eqn. 6)}$$

$$\rho = \frac{R*(\pi*r^2)}{D*\pi*N} \quad \text{(Eqn. 7)}$$

$$R = \frac{\rho*(D*\pi*N)}{\pi*r^2} = 91.837\ \Omega \quad \text{(Eqn. 8)}$$

With a resistance of 91.837 Ω we can now use equation 3 to find the required current.

$$I = \sqrt{\frac{m*c*(T_2-T_1)}{R*t}} = 0.6997\ A \quad \text{(Eqn. 9)}$$

Conclusion

By using equation 8 the resistance of the Nitinol spring was found to equal 91.837 Ω. With this value of resistance all of the necessary variables are known to solve current. Using equation 9 resulted in a current of approximately 0.7 Amps. This is the minimum required current to actuate the spring in 0.5 seconds. Since the current and time are inversely proportional, we can increase the current further to get a quicker actuation time. With these formulas the team can manipulate different variables and know the outcome. One set of variables that are likely to change are the specifications of the Nitinol wire. It is likely that as the designs change, the shape and size of the Nitinol spring will change as well.

This analysis will allow the team to meet General Atomics engineering requirements regardless of design changes in terms of dimensions and other characteristics. Knowing the right current will prevent various critical failures such as overheating wires and the Nitinol spring. If the Nitinol spring were to reach too high of a temperature it may permanently deform and result in a device that cannot release the pin.

References

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