Hold Down Release Mechanism
Team Stellar Hold – GA HDR

Force Analysis and Electrical Revisions

Valentin Gamez

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NORTHERN ARIZONA UNIVERSITY

College of Engineering, Informatics, and Applied Sciences

Project Sponsor: General Atomics – Electromagnetic Systems

Advisor: Pam McCulley

Instructor: David Willy

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1 Introduction

The GA HDRM team's goal is to design and manufacture a hold down and release mechanism for a CubeSat with specific engineering requirements. The requirements with top priority include making the device resettable, no pyrotechnics, and low outgassing. Through research the team discovered Nitinol actuators that would effectively meet all the engineering requirements. Nitinol is a shape memory alloy that can revert to its set shape by increasing the materials temperature.

Designing an effective Nitinol actuator would require analysis on two major components. The first being the forces the nitinol spring would have to overcome in order to find the necessary force output of the spring. This force output will directly impact the dimensions and properties of the spring. The team currently has a Nitinol spring, this spring will be compared to the force requirements to determine whether the team needs a new spring. Secondly, the team needs to briefly revisit the electrical analysis to understand what voltage needs to be applied and how to design the circuit to effectively heat the nitinol spring for activation.

2 Force Analysis

2.1 Assumptions and Variables

Below are all the variables needed for the analysis. Also included are the assumptions and knowns made based off current equipment and materials used.

Variable Definitions:

- F_N = Nitinol Force output
- F_s= Force of opposing spring (N)[1]
- f = Friction force (N)
- y = spring distance (mm)
- k_s = spring constant (N/mm)
- d = diameter of wire (mm)
- D = diameter of spring (mm)
- T_A = temperature required for Austenite state (^{O}C)
- T_M = temperature required for Martensite state (^{O}C)
- N = number of coils (#)
- G_M = Shear Modulus of Martensite (Pa)
- G_A = Shear Modulus of Austenite (Pa)
- M_s = Martensite starting temperature (^{O}C)
- M_f = Martensite finish temperature (^{O}C)
- δ_L = Compressed spring length (mm)

Assumptions:

- k_s = 0.2454 N/mm [2]
- y = 6.0 mm
- T_2= 60 ^{O}C
- T_1 = 30 ^{O}C
- N = 25

- δ_L = 15 mm
- d = 0.7 mm
- D = 9.0 mm
- M_f = 30 (^{O}C)
- M_s = 58 (^{O}C)
- G_M = 83E9 Pa
- G_A = 28E9 Pa

2.2 Analysis

To find the force output needed for the nitinol spring, the entire system needs to be analyzed. The nitinol spring force needs to be greater than or equal to the opposing forces. Figure 1 shows all of the opposing forces in red. F_s is the spring force opposing the nitinol spring is the main contributor. Figure 1 also shows that there are three points for potential frictional forces on each side. Since the team will be using the appropriate surface finishing to minimize friction and there are little forces acting on the x axis, the frictional forces can be neglected. This leaves $F_N = F_S$ since the force of the opposing spring is the only force left.

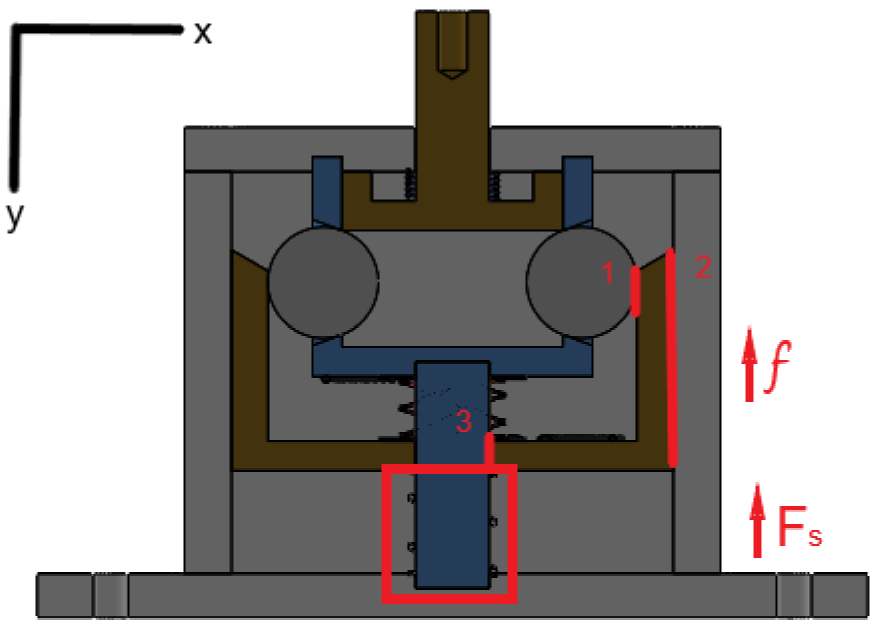

Figure 1:HDRM Free Body Diagram

$$F_N = F_s = ky * 1000^{-1} = 1.472N \qquad \text{(Equation 1)}$$

Using equation 1 (including a conversion factor for mm to m) with the assumptions stated above leads to $F_N = F_s$ = 1.47 N *[3]*. Next is to use an equation that shows the relationship between the force and the geometrical properties of the spring. Equation 2 shows this relationship and can modified to solve for the ratio of the diameters*[4]*. By solving for the ratio of the diameters the team can scale the spring to the appropriate ratio. This ratio is represented in equation 3 and by combining equation 2 and 3 with some algebra gives equation 4.

$$F_N = \frac{G_{max} * d^4}{8 * D^3 * N} * \delta_L \quad \text{(Equation 2)}$$

$$C = \frac{d^4}{D^3} \quad \text{(Equation 3)}$$

$$C = \frac{8 * N * F_N}{G_{max} * \delta_L} \quad \text{(Equation 4)}$$

G_{max} is needed in order to find C, to do this equation 5 will be used. G is at its maximum when T is used as the Austenite temperature, in this case it is 60 °C. G_{max} allows for the maximum force output in the Austenite phase[4]. Equation 6 will be used to find phi in equation 5. After plugging in the previously stated assumptions, G_{max} is equal to 53.88E9 Pa. Plugging everything back into equation 4 leaves C equal to 3.64E-7. Since C is directly proportional to the force of the nitinol spring, the team will need a C value greater than the one calculated. Plugging in the values for our current nitinol spring dimensions into equation 3 gives a C value of 3.29E-7.

$$G_{max} = G_M + \frac{G_A - G_M}{2}[1 + sin\emptyset(T_A - T_M)] = 53.88\ E9\ Pa \quad \text{(Equation 5)}$$

$$\emptyset = \frac{\pi}{M_s - M_f} = 0.1122 \quad \text{(Equation 6)}$$

$$C = \frac{8 * N * F_N}{G_{max} * \delta_L} = 3.64E - 7$$

3 Electrical Analysis Revisions

Due to recent discovers the team needs to reevaluate the circuit design used for actuating the nitinol spring. Imagesco wrote an article on activating nitinol actuators using two methods, a DC circuit and a pulse width modulated electrical current. The article states that a DC circuit may be simpler, but it can lead to overheating the spring and damage its properties. The team observed this during a test but did not make the connection until finding this article. Using a PWM circuit (Figure 2) will fluctuate from on, and off which will all the heat to flow evenly and without damaging the spring[5].

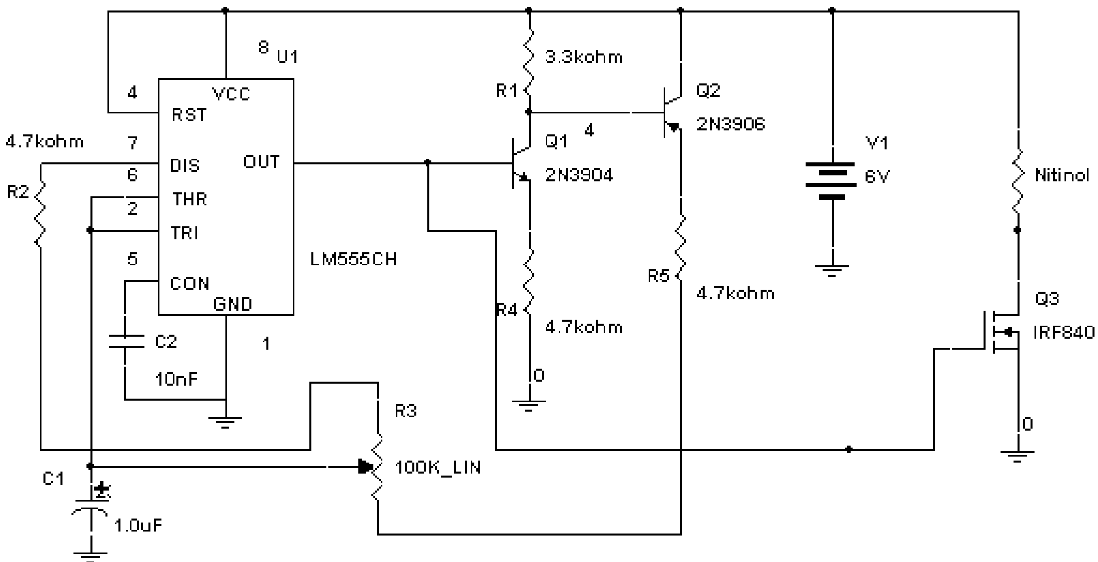

Figure 2: PWM Electrical Circuit [5]

4 Conclusion

After doing a force analysis the results showed that the nitinol spring needed to output 1.47 N. To relate this to the dimensions of the spring equation 2 was used. This allowed the team to relate the force to a ratio (C) of the wire and spring diameter. This was done to scale as needed if the current spring was not strong enough. Plugging in the necessary force led to a C value of 3.64E-7, meaning that any spring the team used had to be greater than this value. After evaluating the team's current spring, it had a C value of 3.29E-7, which is 10% smaller than the minimum value. This means that the team needs to find a spring with a larger wire diameter or a smaller spring diameter. The first option is preferred due to manufacturing costs. As for the electrical circuit the team will change the DC circuit design to a PWM electrical current. This switch will lead to a more time efficient actuation and a longer lasting actuator.

5 References

[1] “Friction - Friction Coefficients and Calculator.” https://www.engineeringtoolbox.com/friction-coefficients-d_778.html (accessed Sep. 16, 2022).

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[3] J. Spring, “What is Spring Constant and How is the Formula Calculated?,” Jun. 04, 2018. https://www.jamesspring.com/news/spring-constant/ (accessed Sep. 16, 2022).

[4] Jianzuo Ma, Haolei Huang, and Jin Huang, “Characteristics Analysis and Testing of SMA Spring Actuator.” Hindawi, Sep. 08, 2013.

[5] “Activating Nitinol with Electric Current.” https://www.imagesco.com/articles/nitinol/07.html (accessed Sep. 16, 2022).