Thermal Characterization of the New Actpacks

Methodology: The thermal model used for thermal characterization is based on the *Cauer thermal network*, which represents heat transfer through a series of thermal resistances and capacitances arranged in a chain. This structure models the flow of heat through successive layers of a system.

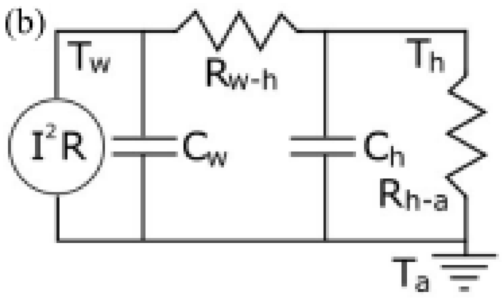

Figure 1: The diagram illustrates the equivalent circuit of the thermal model used to characterize the first version of the Actpack. This model, developed by Gray and Jianping

The parameters of the model indicated in *Figure 1* are as follows:-
Cw: Thermal capacitance of the winding
Ch: Thermal capacitance of the housing
Rw-h: Thermal resistance b/t the winding and the housing
Rh-a: Thermal resistance b/t the housing and ambient environment
T_w: Temperature of the winding
T_c: Temperature of the case
T_a: Temperature of the ambient
I: q-axis Current
R: Resistance of winding to q-axis current

Since this thermal model had previously been used to characterize the earlier version of the Actpack, it was chosen again for the thermal characterization of the new Act-Packs. To analyze the variation in case temperature, q-axis currents of 6 A, 3.5 A, and 4.5 A were applied to the Dephy Drives across three separate tests. Test 1, which used 6 A, ran for 1 hour and 12 minutes, while the other two tests, using 3.5 A and 4.5 A respectively, each ran for 38 minutes. Thermal data was captured using an infrared camera (as shown in Figure 2), and the motor current was logged at 300 Hz using the OSL library.characterization of the new Actpack.

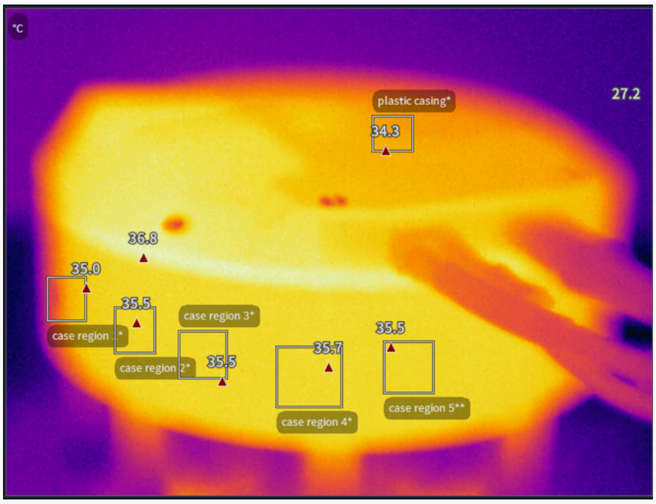

Figure 2: Displays the live feed from the thermal camera. The average temperature within the bounding box was considered, as it encompassed both the plastic and metal sections of the motor casing.

This current profile was then the input to the thermal model, which uses Euler's numerical method to solve a pair of first-order ordinary differential equations (ODEs) governing the system's thermal behavior. The ODEs are as follows:

$$\dot{T}_w = \frac{I_q^2 R_q}{C_w} + \frac{T_h - T_w}{R_{w-h} C_w}$$

$$\dot{T}_h = \frac{T_w - T_h}{R_{w-h} C_h} + \frac{T_a - T_h}{R_{h-a} C_h}$$

The time step for numerically solving the two ODEs was set to dt = 1/300 seconds, corresponding to the inverse of the update frequency. This allowed the model to generate predicted values of Tw and Th at each time step. The predicted Th values were then used to plot their variation over time. This predicted temperature profile was compared against the actual housing temperature data recorded by the thermal camera, effectively showing the rise in housing temperature over time alongside the model's prediction. The thermal camera records the temperature at 30 Hz; interpolation was used to get the two data points on the same time scale, and the data was plotted in one graph.

Results and Discussion:

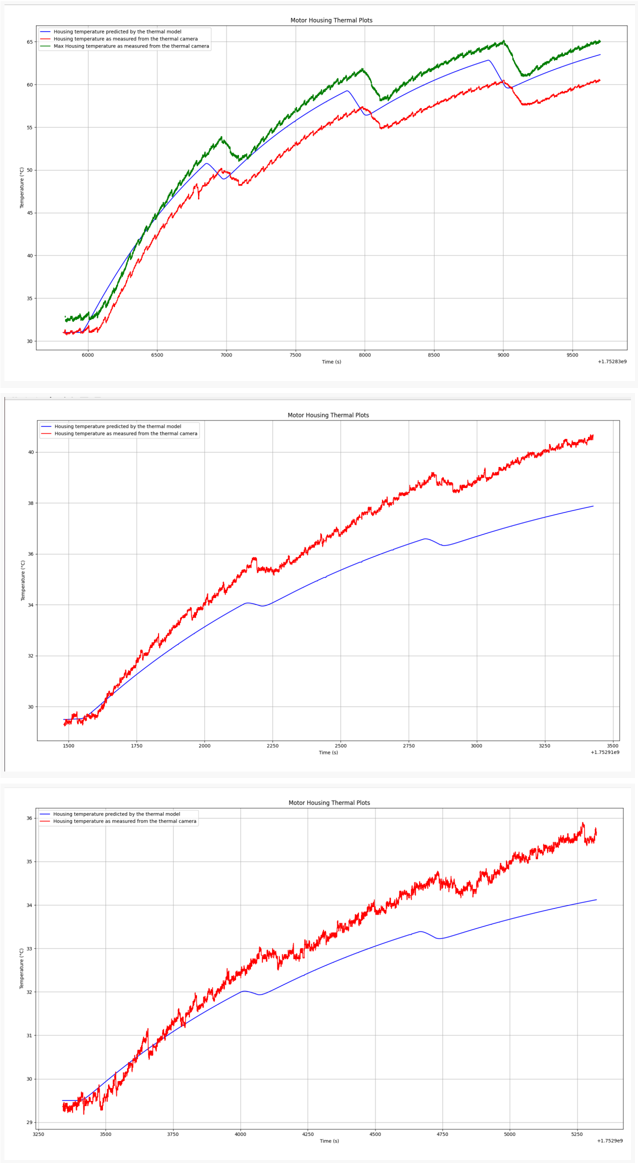

Figure 3: The images above illustrate the variation in case temperature across all three cases. It is evident that the temperature rise observed using the thermal camera closely aligns with the predictions made by the model.

The thermal model developed for the first version of the ActPack is applicable to the third version of the AK80-9 as well. Despite using the same architecture, the newer motors offer a higher torque constant while exhibiting thermal behavior that closely matches the original ActPack.

References:

[1] U. H. Lee, C. -W. Pan and E. J. Rouse, "Empirical Characterization of a High-performance Exterior-rotor Type Brushless DC Motor and Drive," *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Macau, China, 2019