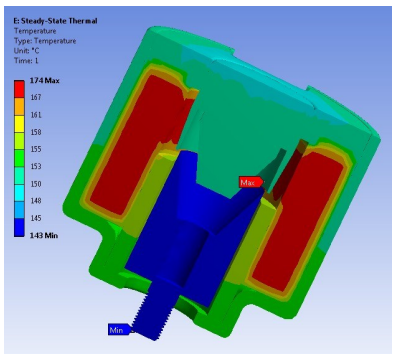
SOLENOID SYSTEMS

A CASE STUDY FROM SOLENOID SYSTEMS

Analyzing the Thermal Operating Conditions of a Solenoid

BACKGROUND



When designing a Solenoid the operating temperature of the Coil must be taken into account when assessing the Solenoid's performance. As the Solenoid's Coil temperature increases due to ambient conditions or self heating the resistance of the coil also increases, reducing the current draw for a given supply voltage. A reduction of current reduces the magnetomotive force output of the coil (Coil Turns x Amps) which reduces the Solenoid Force output.

The specifications for this application are as follows:

- Solenoid Stroke = 7mm
- Solenoid Force = 6.25 Newton minimum across Stroke and under all operating conditions
- Minimum Operating Voltage = 9.8 V
- Maximum Ambient Temperature = 140 C
- Short Circuit = 18V applied to the Coil terminals for 15 minutes at 20C ambient. Solenoid must produce Solenoid Force at Minimum Operating Voltage.
- Continuous Duty = 13.4V applied to the Coil terminals at 100C ambient. After steady state temperature is reached the Solenoid must produce Solenoid Force at Minimum Operating Voltage.

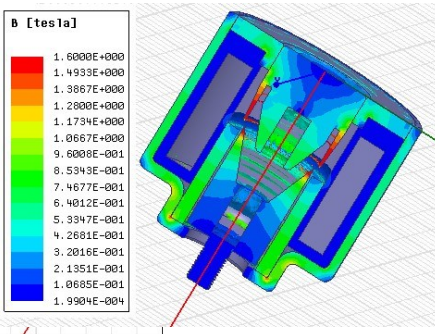
Based on the above specifications there are three thermal operating conditions to consider:

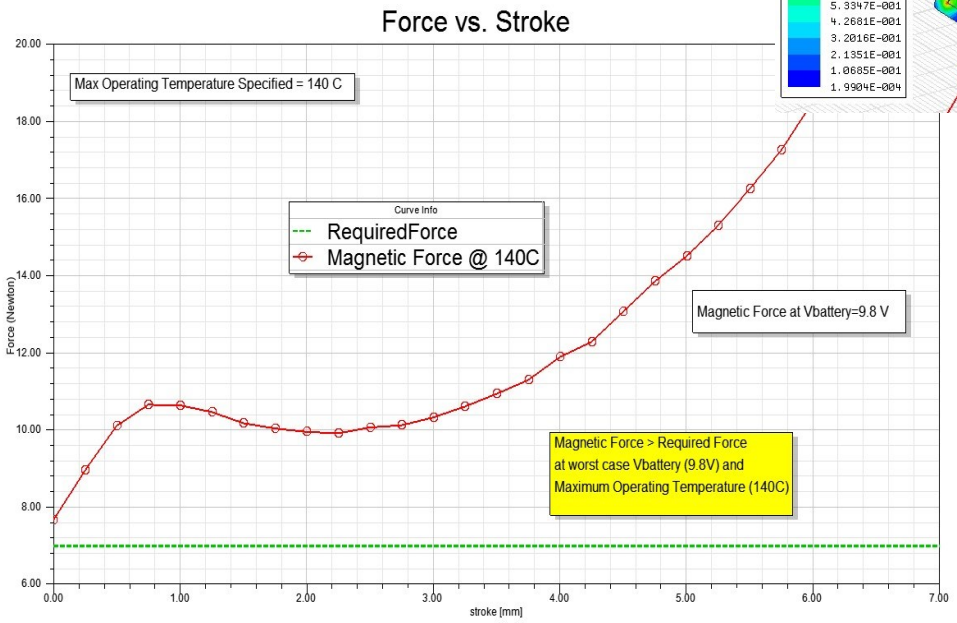
1. Maximum Ambient - Coil Temperature is known. In this case it is 140C.
2. Short Circuit - Coil Temperature is unknown and requires a thermal analysis.
3. Continuous Duty - Coil Temperature is unknown and requires a thermal analysis.

Since the Coil Temperature is known for Condition #1 (Maximum Ambient), a design will start with this operating point. The design will then be analyzed with the other two thermal operating conditions.

INITIAL DESIGN

An initial design is created to satisfy Thermal Condition #1 - 140C Ambient and the minimum magnetic force requirement of 6.25 N across a 7mm stroke. The design process is not covered in the case study. The 3D design is imported into Solenoid System's Virtual Development Platform for magnetic analysis.

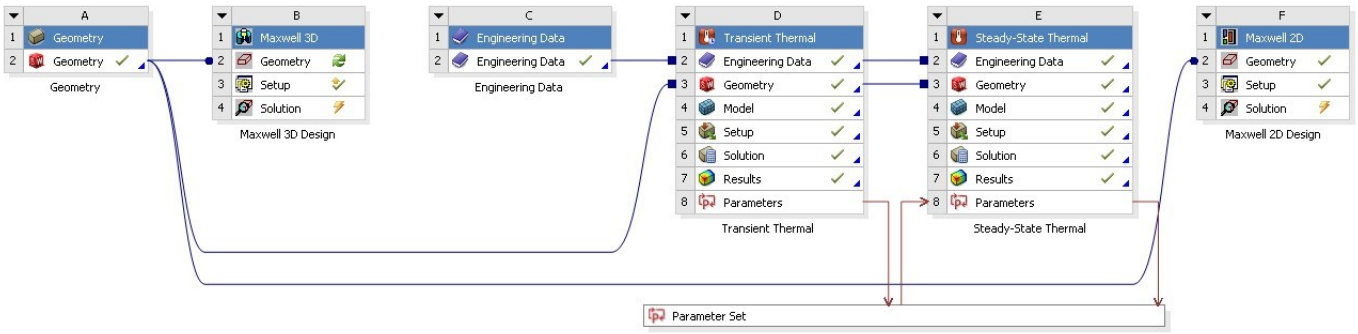




This design satisfies the force requirements at the Maximum Ambient Temperature of 140C with the Minimum Supply Voltage of 9.8 V. The design needs to be analyzed for the other two thermal conditions to verify that the force requirements are still satisfied.

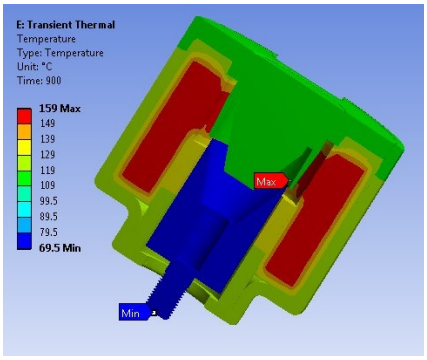
THERMAL ANALYSIS

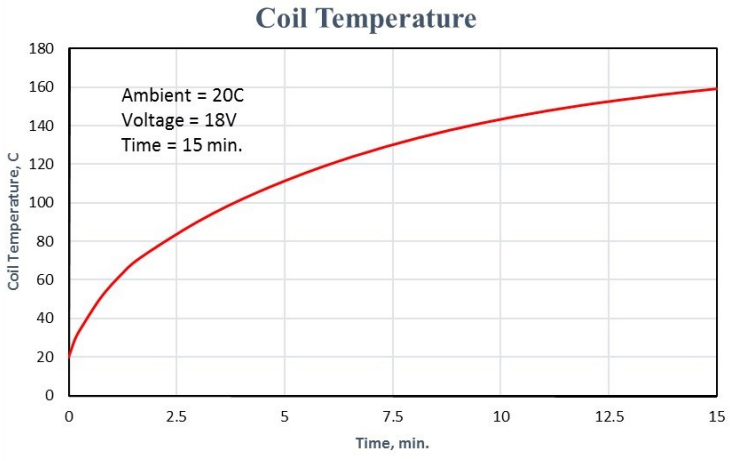
In order to determine the Coil temperature for thermal conditions #2 and #3, a Transient and Steady State Thermal analysis will be setup and performed within Solenoid System's Virtual Development Platform as seen below.



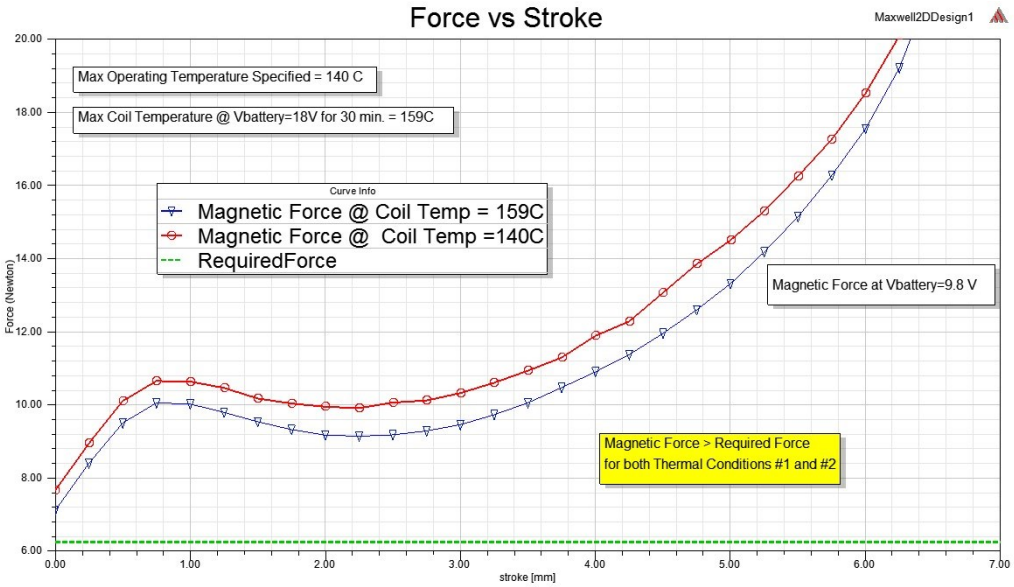
Condition #2 - Short Circuit

A Transient Thermal analysis was performed on the design, applying 18V to the Solenoid for 15 minutes at an ambient temperature of 20C. Below is a plot of the Coil Temperature vs. Time and a cross section showing the temperature gradient though the Solenoid.





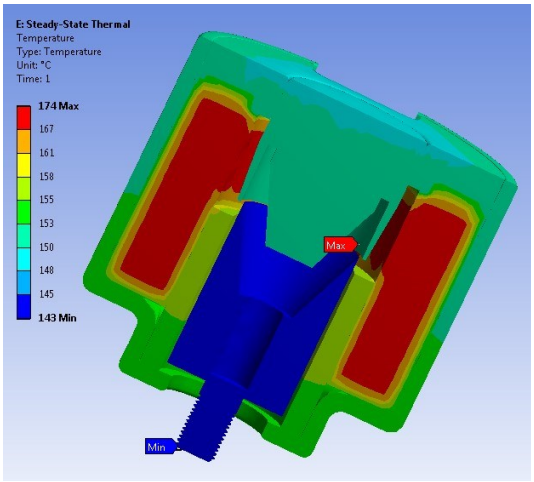
The Coil temperature reaches a temperature of 159 C after 15 minutes. This temperature is input back into the magnetic analysis to analyze the force vs stroke performance. The graph below shows that the force requirements are still satisfied at 159C. If the force requirements were not met for this thermal condition a redesign would be required.



Thermal Condition #3 is now analyzed to determine if the design satisfies all three thermal operating conditions.

Condition #3 - Continuous Duty

A Steady State Thermal analysis was performed on the design, applying 13.4 V to the Solenoid at an ambient temperature of 100C until thermal equilibrium was achieved. The Coil Temperature as seen in the cross section below reached 174C.

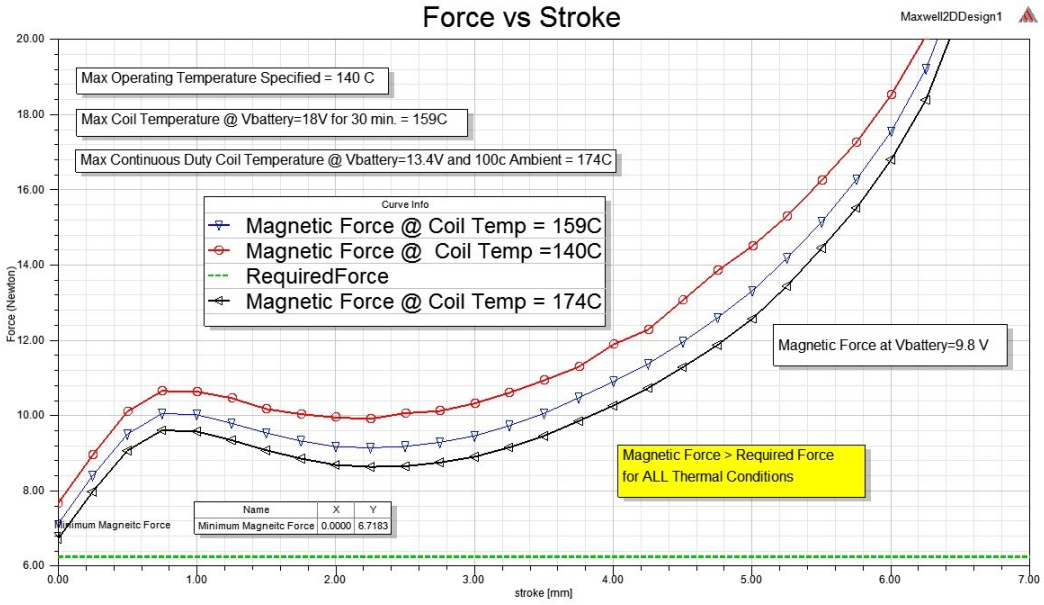


Magnet Wire Considerations

With a maximum Coil temperature of 174C the insulation material of the magnet wire must be taken into consideration. There are three common magnet wire insulation classes; 150C, 180C and 200C. The 150C and 180C class of magnet wires do not need to be mechanically or chemically stripped before soldering to the coil terminals. Some insulation grades of 180C wire do however require a higher soldering temperature.

The 200C class of magnet wire requires the insulation to be removed prior to soldering. This can be done thermally (as in Flame Soldering), mechanically or chemically. This class of magnet wire is typically resistance welded to the coil terminals. Therefore, the maximum temperature of the Solenoid Coil not only effect performance but the type of magnet wire specified and the manufacturing process.

The design was analyzed with a Coil temperature of 174C and the minimum magnetic force occurs at ZERO stroke and is 6.7 N, therefore, the design satisfies this and all thermal operating conditions.



SUMMARY

It is important to identify and analyze all thermal operating conditions to verify the Solenoid's performance and to identify which thermal class of magnet wire is required.

The initial design had enough Force margin with the Coil at 140C that there were no design changes required after analyzing the Short Circuit and Continuous Duty requirements which produced Coil temperature of 159C and 174C respectively.

With a maximum Coil temperature of 174C the thermal class of 180C magnet wire is required for this design.