MECH 420 – Lab Report 5

Kyle Ah Von #57862609

Part A

1) Find the actuator force $F(x_{SA})$ as a function of position for both coil currents and provide a graph with the curves for $F(x_{SA})$ for both current values.

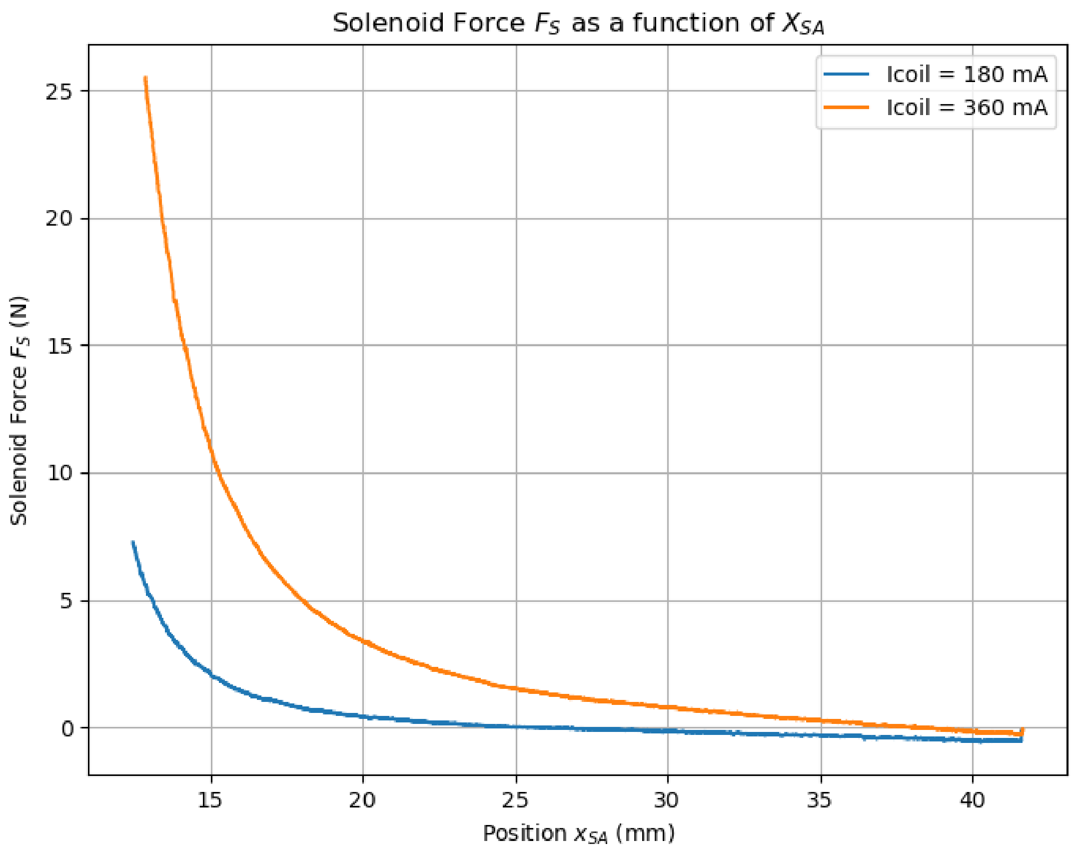

Figure 1: Solenoid Force vs Displacement

The force can be obtained by converting the load cell reading into force considering the zero offset as well. The shape of the curve is characteristic of an inverse squared relationship scaled by the square current value.

$$F_s(x_{SA}) = \frac{dW}{dx_{SA}}\Big|_{I=const} = \frac{d(\frac{1}{2}\, L\, I^2)}{dx_{SA}}$$

$$= \frac{I^2}{2} d\left(\frac{N^2}{a + b\, x_{SA}}\right) / dx_{SA} \; = \; -\, I^2 N^2 b / (2(a \,+\, b\, x_{SA})^2)$$

2) Determine an expression for $F(X_{SA}, I_{coil}) = C_1 I_{coil}{}^2 / (C_2 + X_{SA})^2$ for either current. Comment on how well these relationships fit the measured data. How do the constants C_1 and C_2 compare?

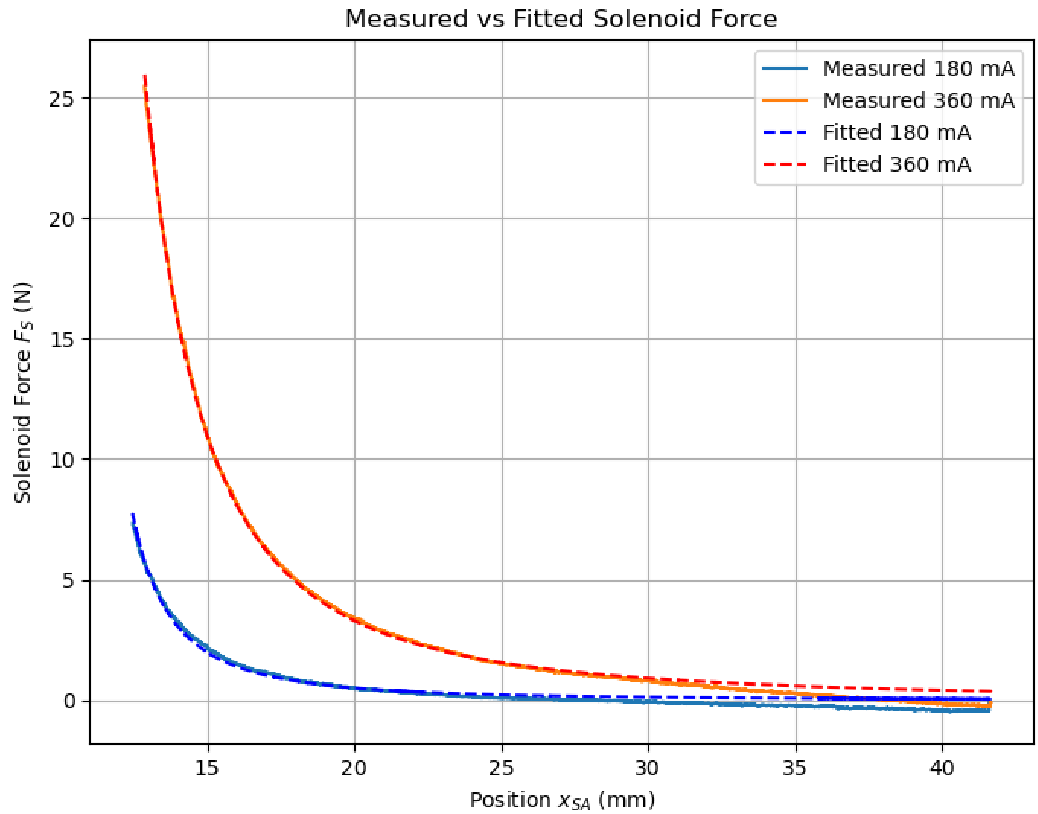

Figure 2: Fitted Curves

Using the suggested equation $F = C_1 I_{coil}{}^2 / (C_2 + X_{SA})^2$.

We can the following parameters:

Parameters for 180 mA: $C_1 = 0.002$, $C_2 = -9.845$

Parameters for 360 mA: $C_1 = 0.003$, $C_2 = -8.925$

Using the mean values, we can determine a equation of $F = 0.0025 \, I_{coil}{}^2 / (-8.0 + X_{SA})^2$

From figure 2, the see that the starts to diverge from the curve fit towards larger positions. It might be due to lower sensitivity at those distances, since a change in displacement yields a smaller change in force.

The constants for both current values are similar with C_1 being around 0.0025 and C_2 around -8. Hence, the shape of the curves is determined primarily by the coil current.

3) Compare your findings with the force vs. position data from the data sheet.

Considering the pull model of the solenoid actuator, this is the force profile:

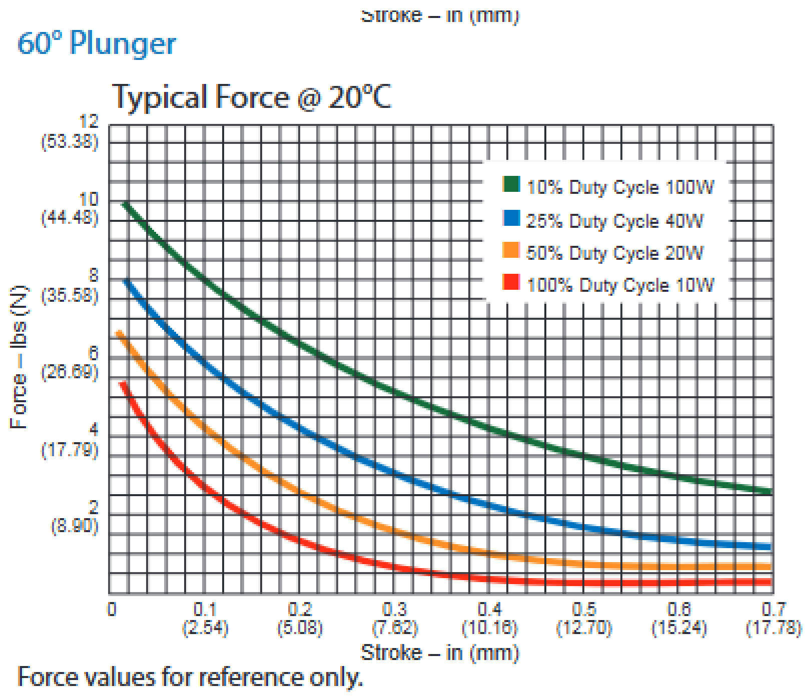

Figure 3: Datasheet force profile

Both the datasheet and measured curves display a similar exponential decay in force as the stroke length increases. This is typical for solenoids, where the force is strongest at shorter strokes and diminishes rapidly as the stroke increases.

The measured peak forces for 180 mA or 360 mA do not align well with the general shape and magnitude of the datasheet's curves for higher-duty cycles (e.g., 100% duty cycle at 100 W). However, the specific peak values and slopes may differ slightly due to variations in current, measurement conditions, or specific solenoid properties.

The force values in the measured graph are scaled based on the solenoid's driving current (e.g., 180 mA and 360 mA), while the datasheet uses different duty cycle and power combinations. Direct equivalence is difficult without knowing the exact power output or electrical properties of the tested solenoid.

The fitted curves in the second image show good alignment with the measured data, indicating the modeling approach accurately represents the solenoid's force behavior for the given input currents.

At larger stroke lengths, the measured and fitted curves show lower residual forces compared to the datasheet. This could be due to differences in measurement precision, solenoid-specific factors, or idealized assumptions in the datasheet data.

4) Find the coil resistance $R(X_{SA})$ for the different coil current values I_{coil} and provide a graph.

Using $R = \frac{V}{I}$, we can find the resistance for corresponding coil voltage and coil current as shown below:

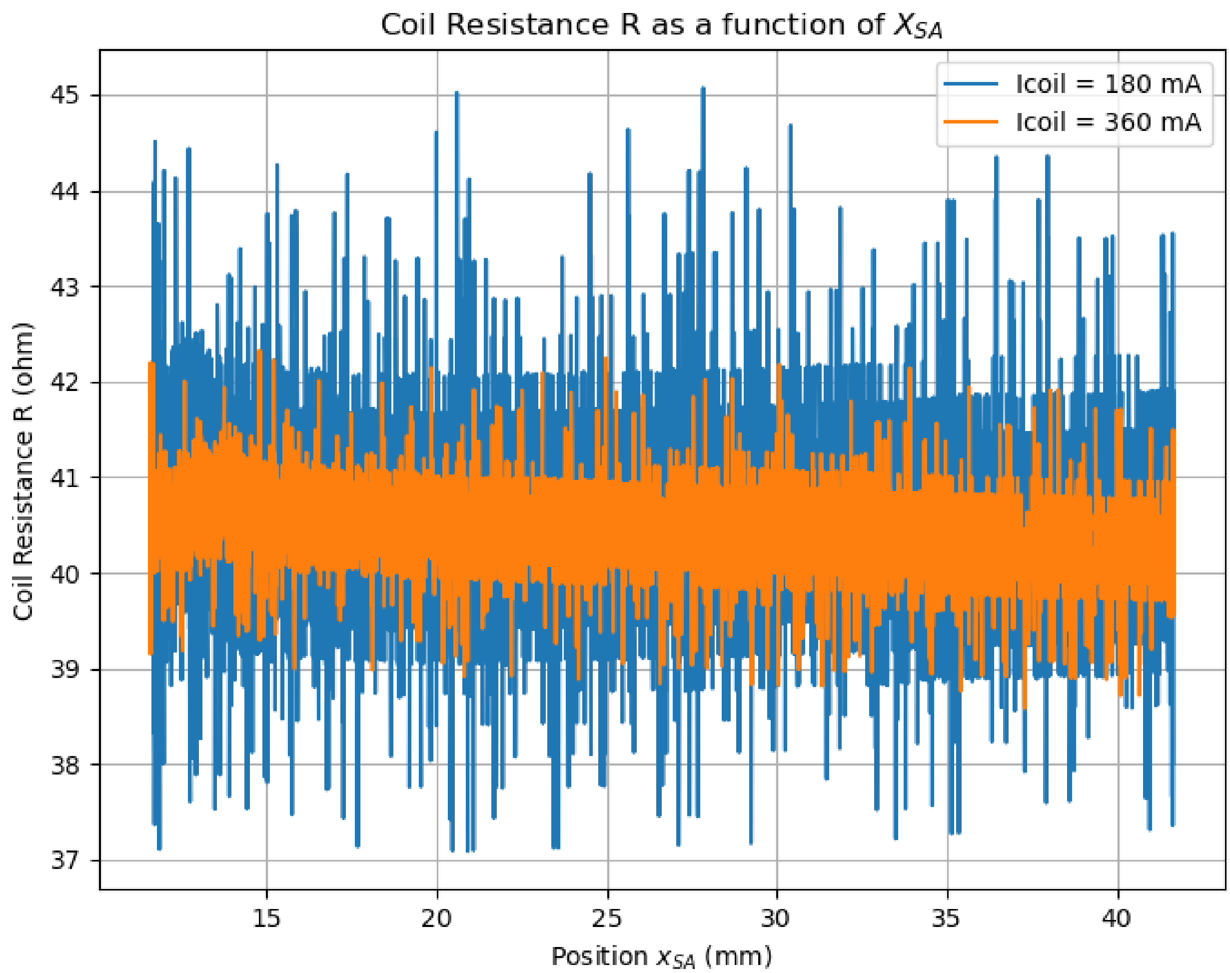

Figure 4: Resistance with Position

The mean values of resistance for a coil current of 180 mA and coil current of 360 mA are 40.5 Ω. Since both coil currents yield the same resistance value, we can say that the resistance is constant.

5) Compare your findings with R from the data sheet.

The difference between the datasheet resistance (77 ohms) and the measured resistance (40.5 ohms) is likely due to a combination of factors. The datasheet value is typically specified at a standard temperature (e.g., 20°C), and since most conductor's resistance increases with temperature, a cooler measurement condition would result in lower resistance. Additionally, manufacturing tolerances, such as variations in wire gauge, winding count, or production batch differences, can cause resistance discrepancies. Datasheet values may also include rounding or represent nominal averages. Measurement errors, such as unaccounted contact resistance or instrument calibration issues, could further contribute.

Part B

1) Calculate the complex $|Z|(f)$ for both positions.

$$Z(\omega) = R + j\omega L$$

$$|Z|(\omega) = \sqrt{R^2 + (\omega L)^2}, with\ \omega = 2\pi f$$

$$|Z|(f) = \sqrt{R^2 + (2\pi f L)^2}$$

2) With R from Part A, find the inductance L for both positions through an appropriate curve fit. You may see that the inductance deviates significantly from its expected behaviour at high impedances, and you might want to exclude this region from the fitting routine.

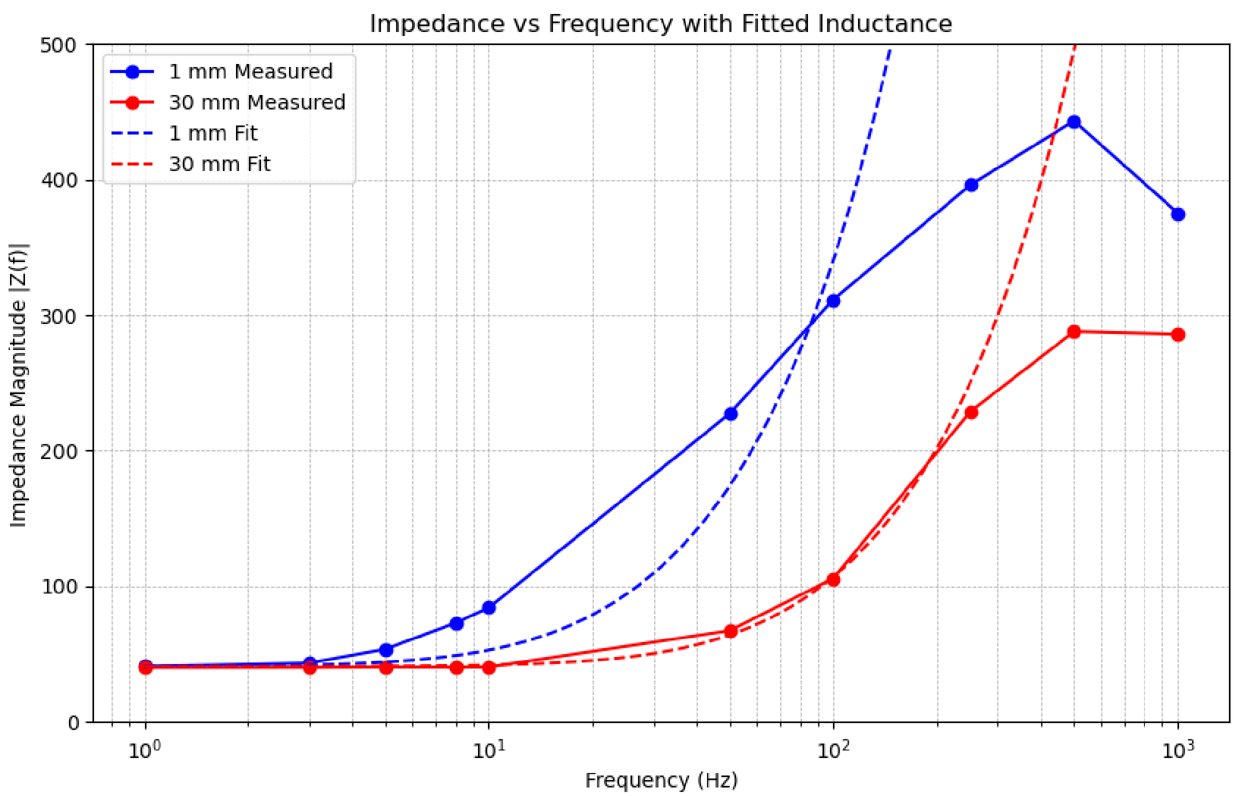

Figure 5: Impedance vs Frequency with fitted curves

After finding the according impedance for different frequencies, we can plot the magnitude with respect to the corresponding frequency for each current value. By fitting a curve using the model function of $y = \sqrt{R^2 + (2\pi x L)^2}$ with the corresponding L values of:

Inductance at 1 mm: 0.538247 H

Inductance at 30 mm: 0.157347 H

3) Compare L for both positions and relate your observation to the relationship between inductance and reluctance and the dependence of the reluctance on position.

The inductance of the solenoid decreases significantly from 0.538247 H at 1 mm to 0.157347 H at 30 mm. This change can be explained by the relationship between inductance L and reluctance R_m where $L = \frac{N^2}{R_m}$ (with N being the number of turns). Reluctance is inversely proportional to the permeability and directly proportional to the length of the magnetic path. At 1 mm, the magnetic path is shorter, resulting in lower reluctance and higher inductance. As the position increases to 30 mm, the air gap grows, increasing the reluctance, which reduces the inductance. This illustrates how the position affects the magnetic circuit's reluctance and, consequently, the solenoid's inductance.