ELECENG 3EY4: Electrical System Integration Project

Lab04_Electronic Speed Controller

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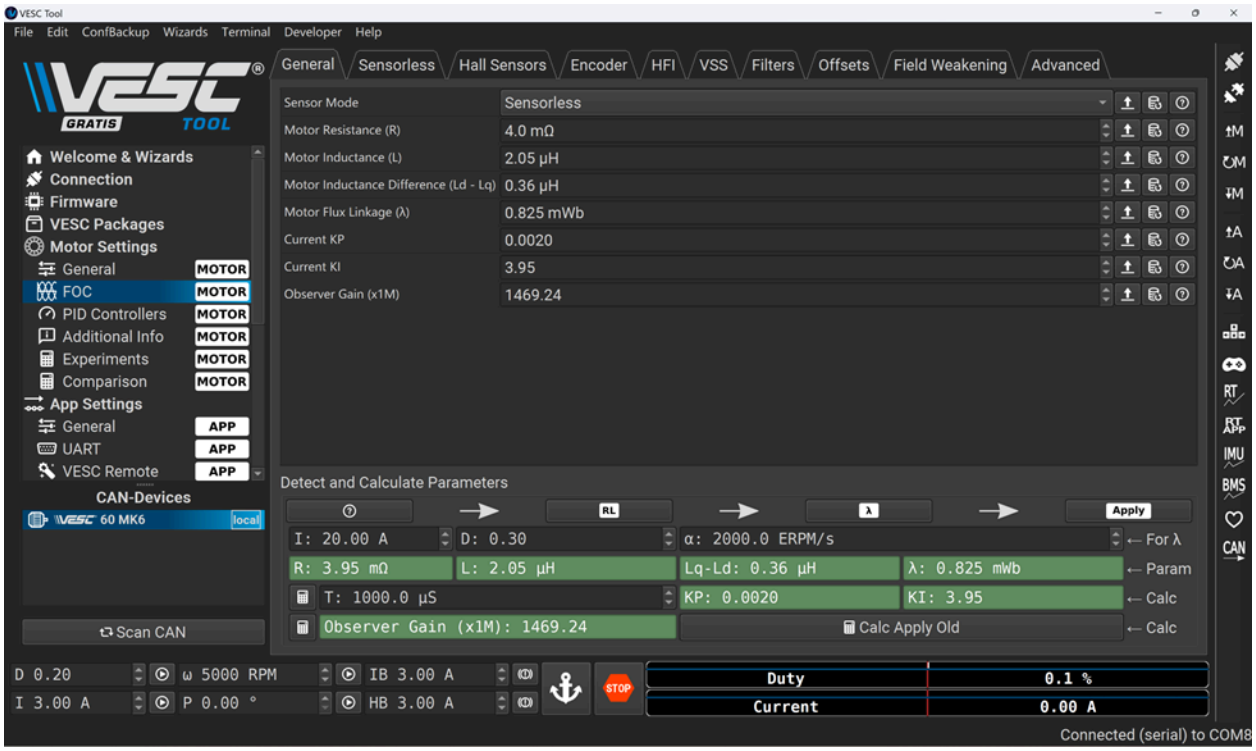
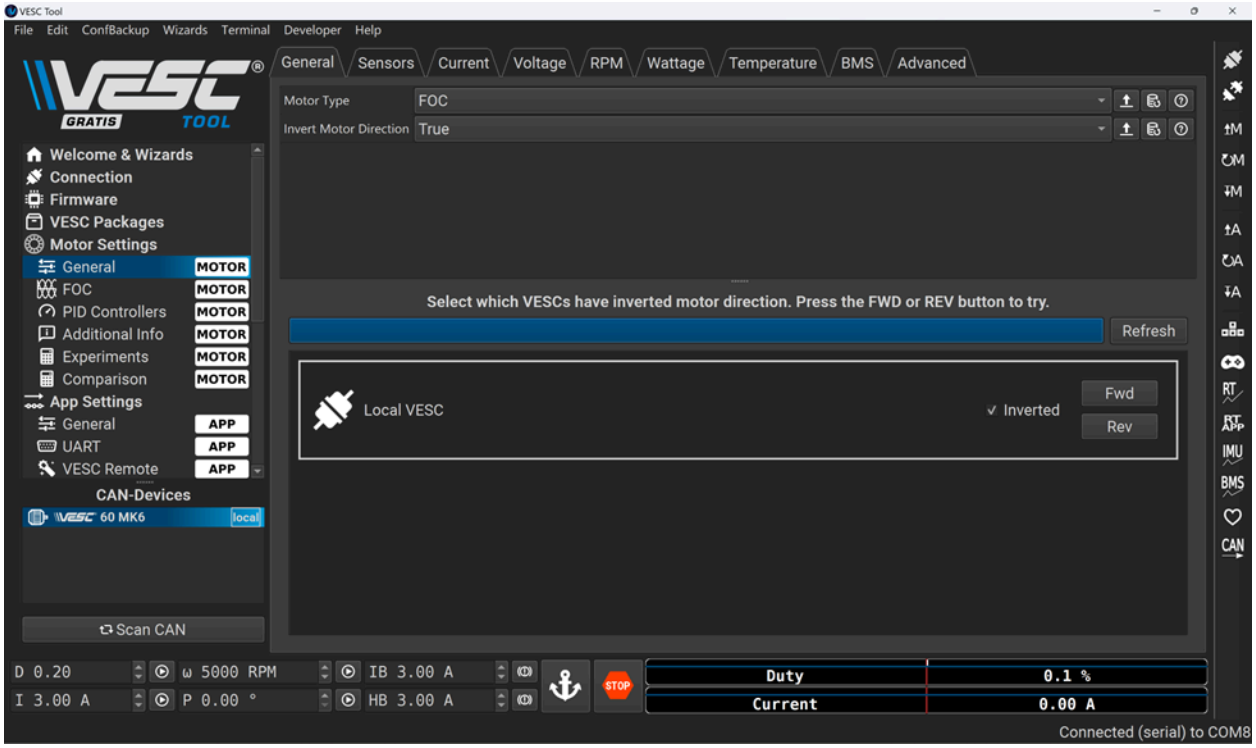
Objective 1: Review of the Lab Manual

For Question 1-3, Yichen Lu led it.
For Question 4-6, Junbo Wang led it.
For Question 7-9, Preet Batra led it.

Question 1: What do those parameters represent? Why are those parameters essential to control the motor?





D represents the duty cycle.
α represents the acceleration speed of the motor, in ERPM per second.
R represents the motor resistance.
L represents the motor inductance.
Ld-Lq represents the motor inductance difference.
λ represents the motor flux linkage.
T represents the time constant for calculating KP and KI.
KP and KI are the gains of the PI controller, KP represents the proportional part while KI represents the integral part.
Observer Gain (x1M) is used to estimate the motor's speed and car's position.

As shown in the equation, T=3/2*λpm*pp*Iq (pp stands for pole pair). We can use the above parameters to calculate the torque, which is essential to control the motor.

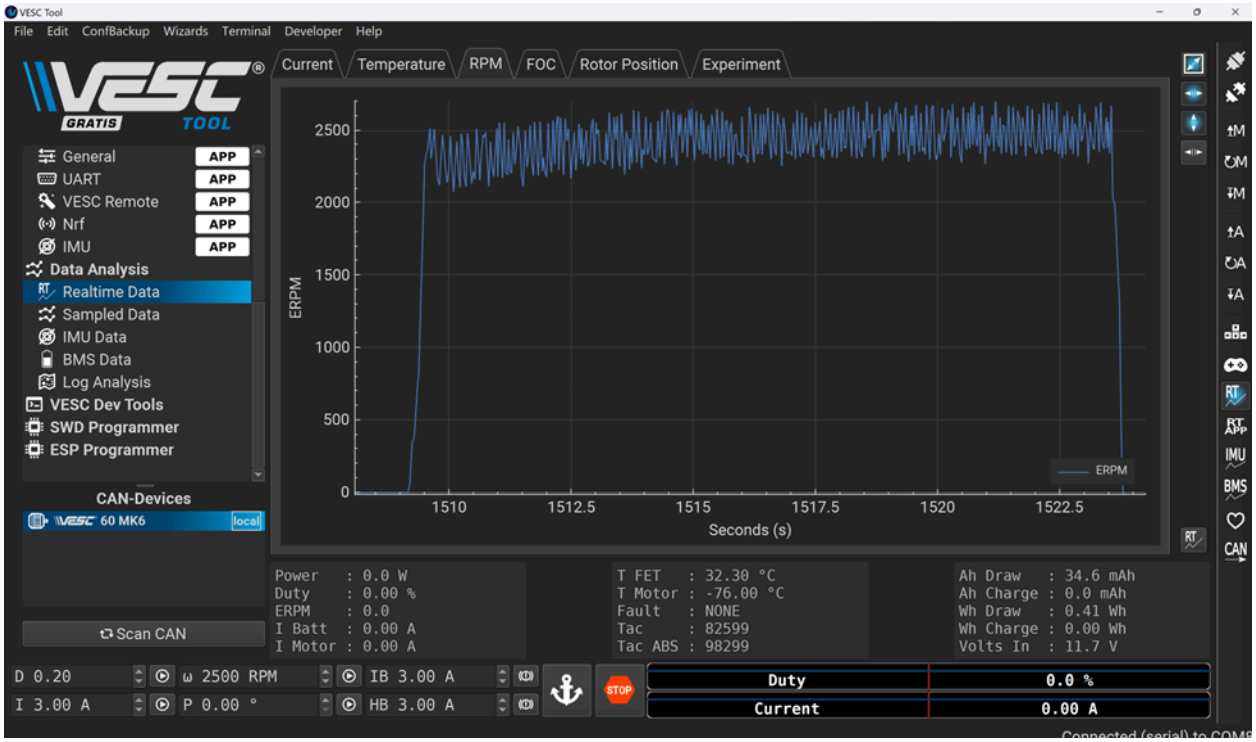
Question 2: Explain the importance of PID speed control parameters in relation to the operation of McMaster AEV?

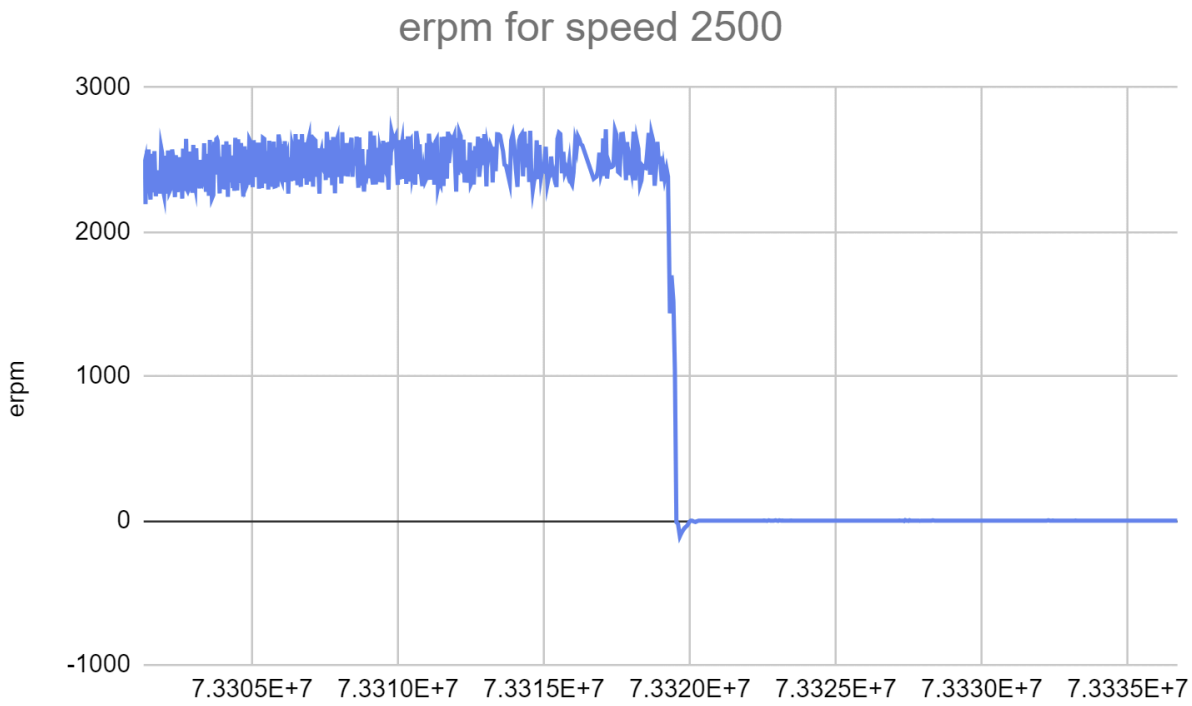
The PID speed control ensures that the vehicle maintains a stable and desired speed. Additionally, it responds appropriately to changes in load, road gradients, or other

dynamic factors. Moreover, it balances between quick response time (minimizing lag) and stability (avoiding overshooting and oscillations). Lastly, it deals with various disturbances and uncertainties that can affect the vehicle's performance. Therefore, proper adjustment of the PID parameters (P, I, D gains) is important for efficient and safe operation of AEV. This involves finding the right balance where the vehicle responds quickly to changes, maintains steady speeds under varying conditions, and minimizes fluctuations and overshoots.

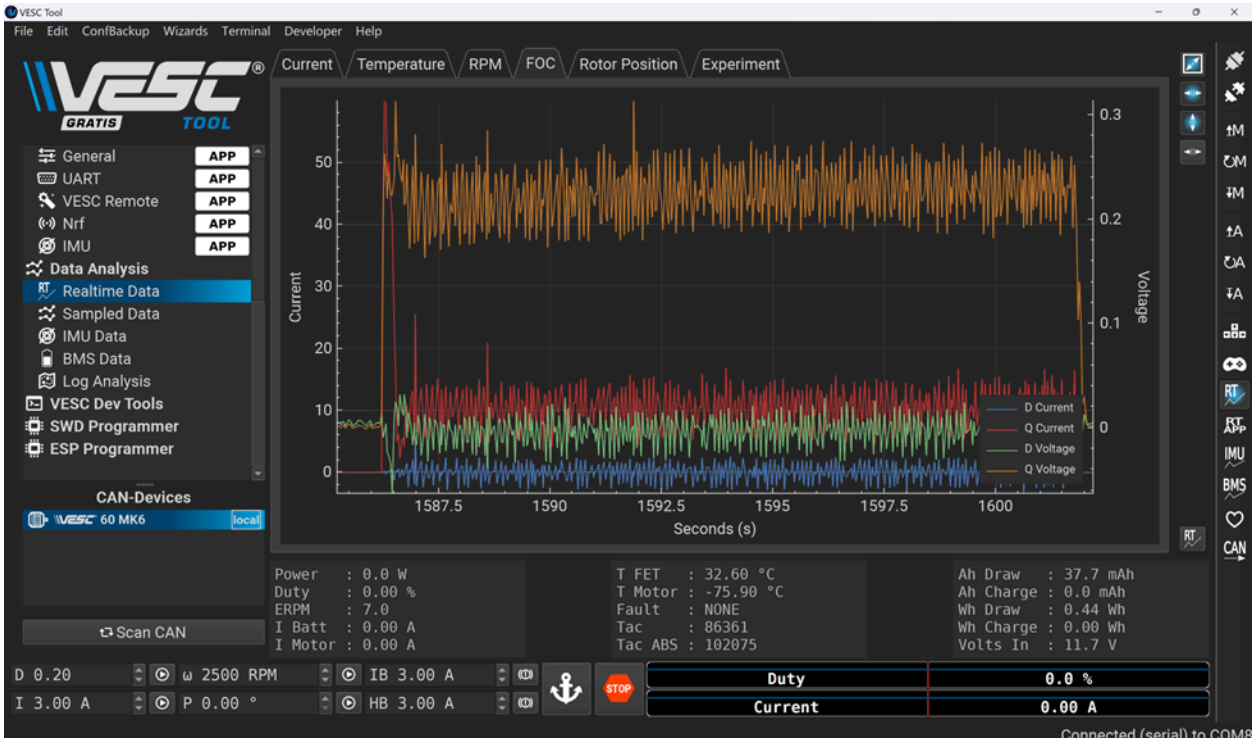
Question 3: First apply speed command to VESC and record how the speed, current and voltage change in time. Please change the speed gradually to a maximum speed command of 7500 rpm (Recommended: start with a speed of 2500, then 5000 and finally 7500 rpm, Take a screenshot of Your RPM and FOC graphs. Log your data for each speed point and plot the graphs for RPM, FOC current (d- and q-axis currents), FOC voltage (d- and q-axis voltages).

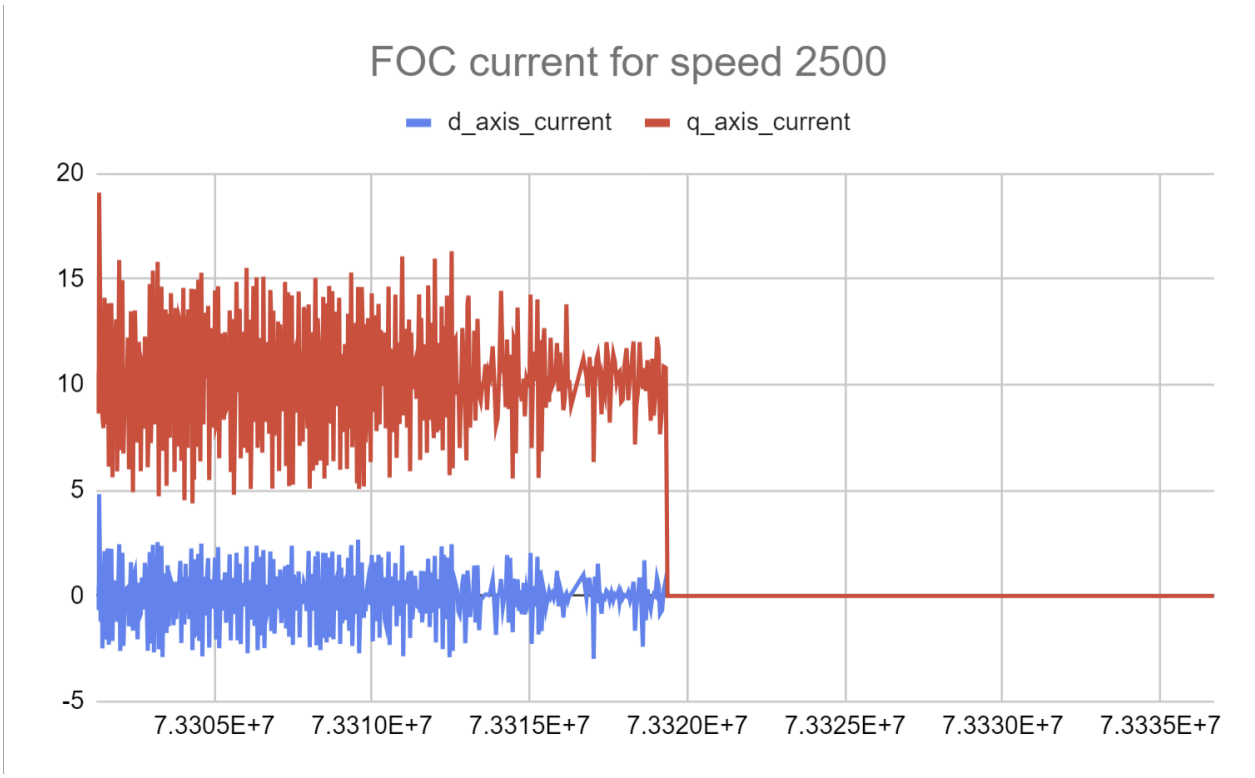
Speed 2500
RPM

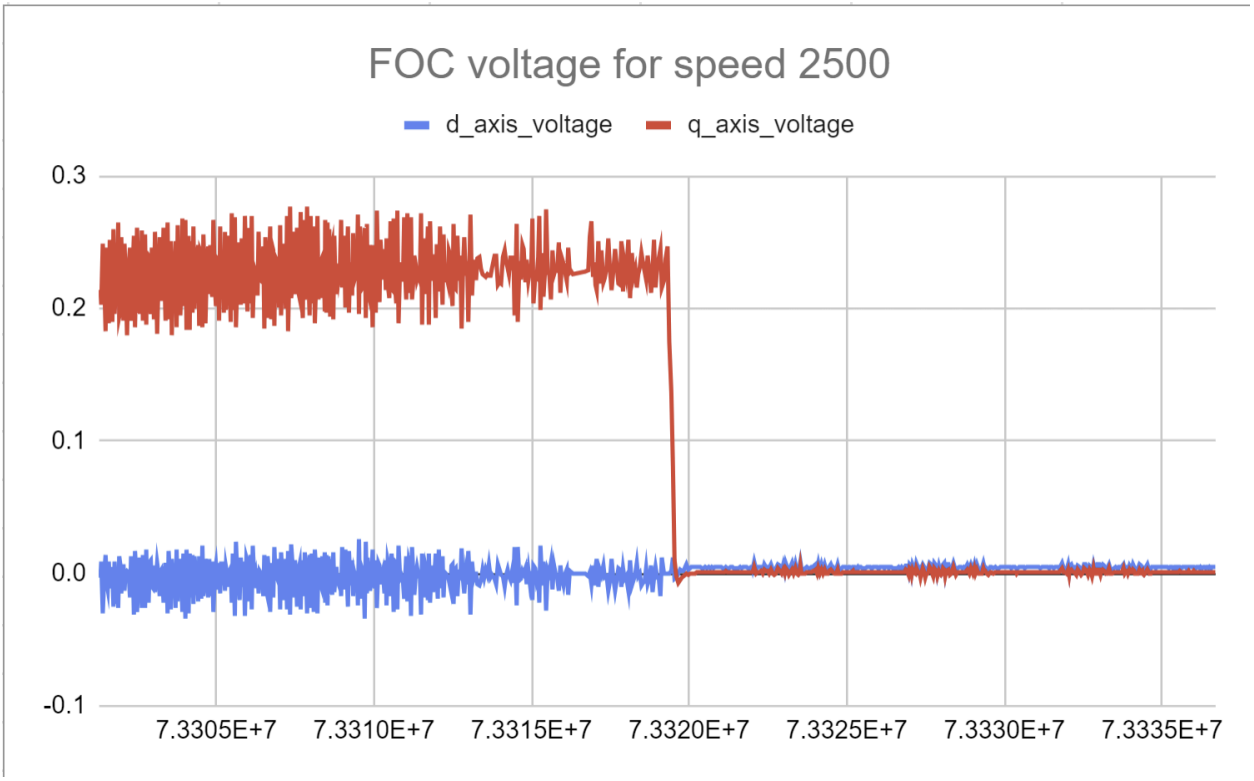



erpm for speed 2500
3000
2000
1000
0
-1000
erpm
7.3305E+7
7.3310E+7
7.3315E+7
7.3320E+7
7.3325E+7
7.3330E+7
7.3335E+7

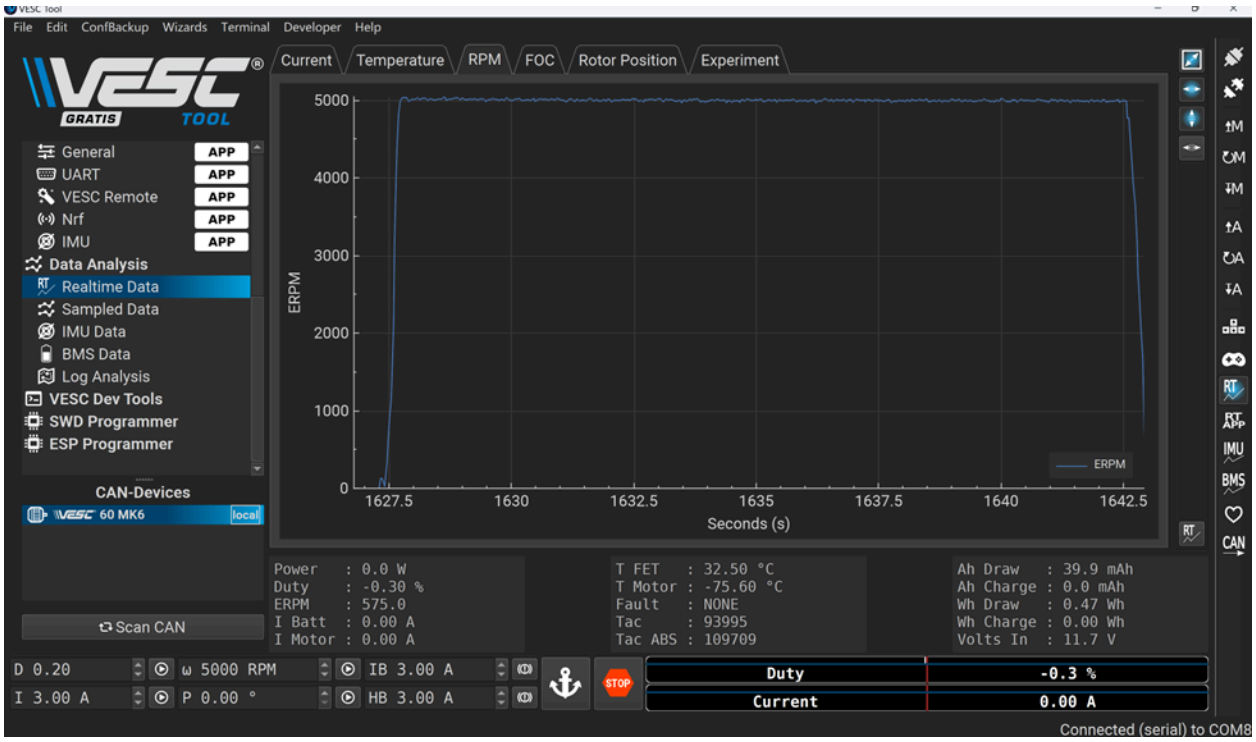
FOC

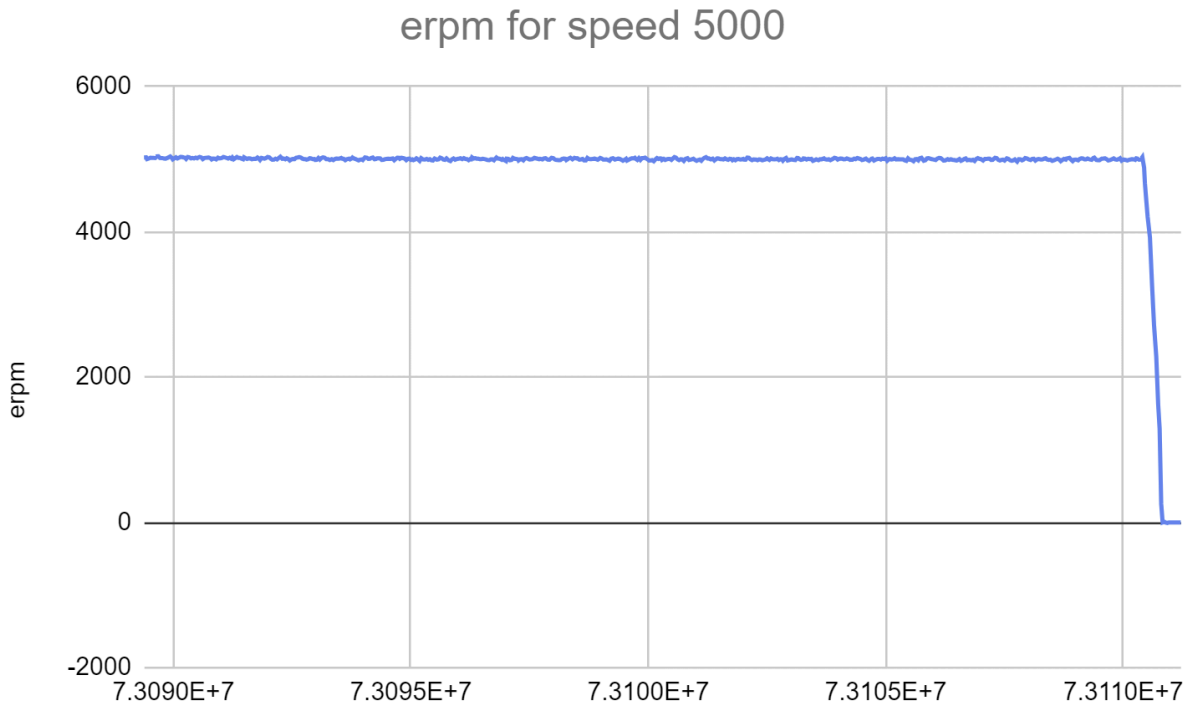

VESC Tool
File Edit ConfBackup Wizards Terminal Developer Help
Current Temperature RPM FOC Rotor Position Experiment
General APP
UART APP
VESC Remote APP
Nrf APP
IMU APP
Data Analysis
Realtime Data
Sampled Data
IMU Data
BMS Data
Log Analysis
VESC Dev Tools
SWD Programmer
ESP Programmer
CAN-Devices
60 MK6 local
Scan CAN
Current
Voltage
Seconds (s)
D Current
Q Current
D Voltage
Q Voltage
Power : 0.0 W
Duty : 0.00 %
ERPM : 7.0
I Batt : 0.00 A
I Motor : 0.00 A
T FET : 32.60 °C
T Motor : -75.90 °C
Fault : NONE
Tac : 86361
Tac ABS : 102075
Ah Draw : 37.7 mAh
Ah Charge : 0.0 mAh
Wh Draw : 0.44 Wh
Wh Charge : 0.00 Wh
Volts In : 11.7 V
D 0.20
ω 2500 RPM
IB 3.00 A
I 3.00 A
P 0.00 °
HB 3.00 A
STOP
Duty 0.0 %
Current 0.00 A


FOC current for speed 2500
d_axis_current
q_axis_current
20
15
10
5
0
-5
7.3305E+7
7.3310E+7
7.3315E+7
7.3320E+7
7.3325E+7
7.3330E+7
7.3335E+7

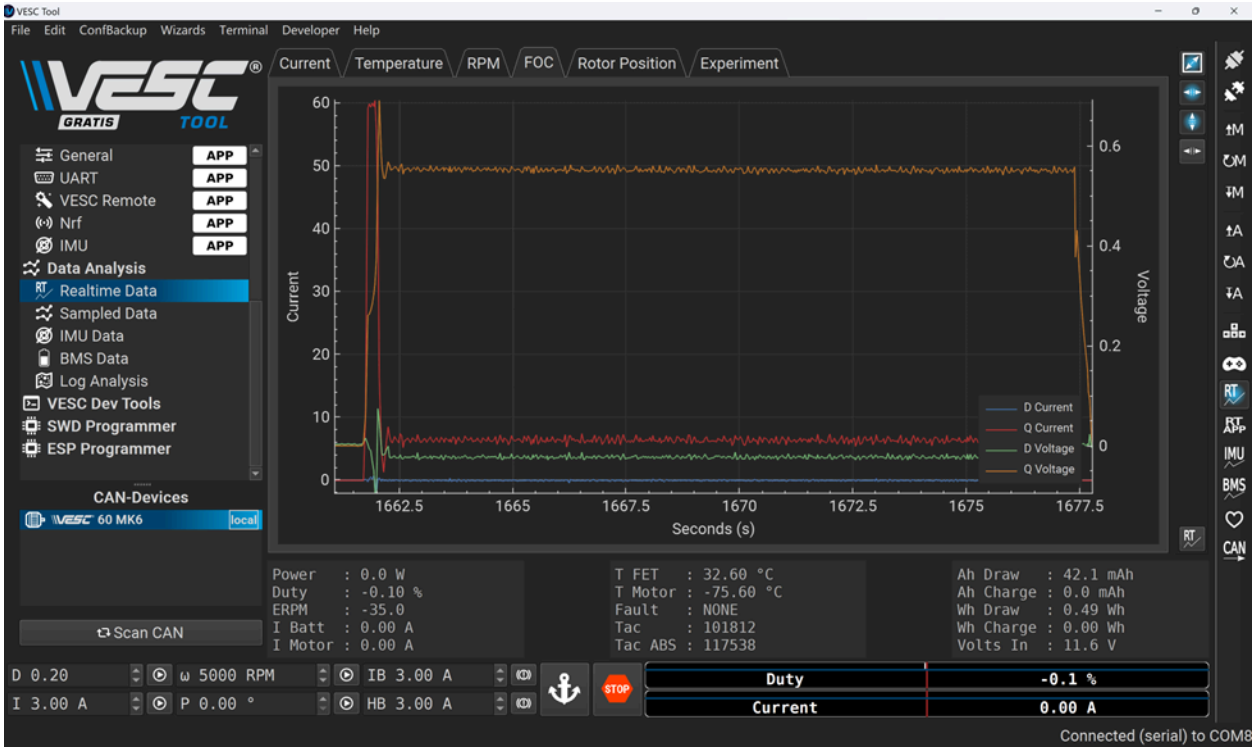

FOC voltage for speed 2500
d_axis_voltage
q_axis_voltage
0.3
0.2
0.1
0.0
-0.1
7.3305E+7
7.3310E+7
7.3315E+7
7.3320E+7
7.3325E+7
7.3330E+7
7.3335E+7

Speed 5000
RPM





FOC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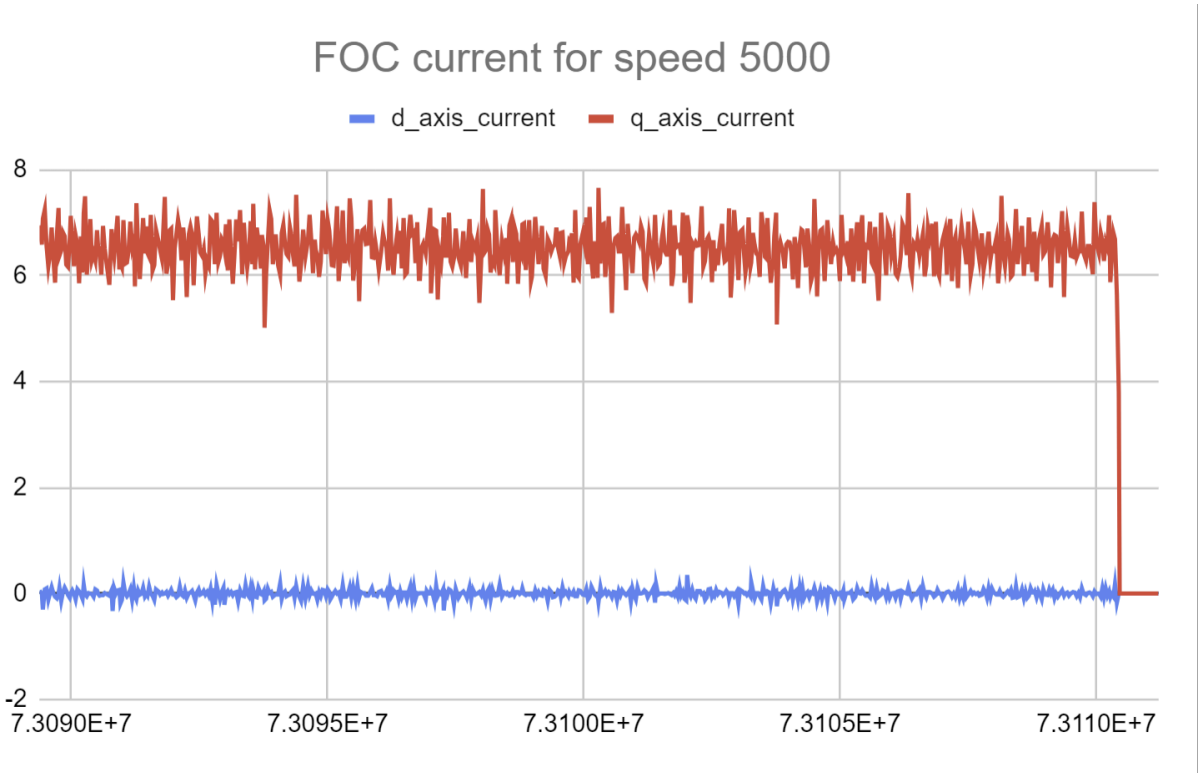
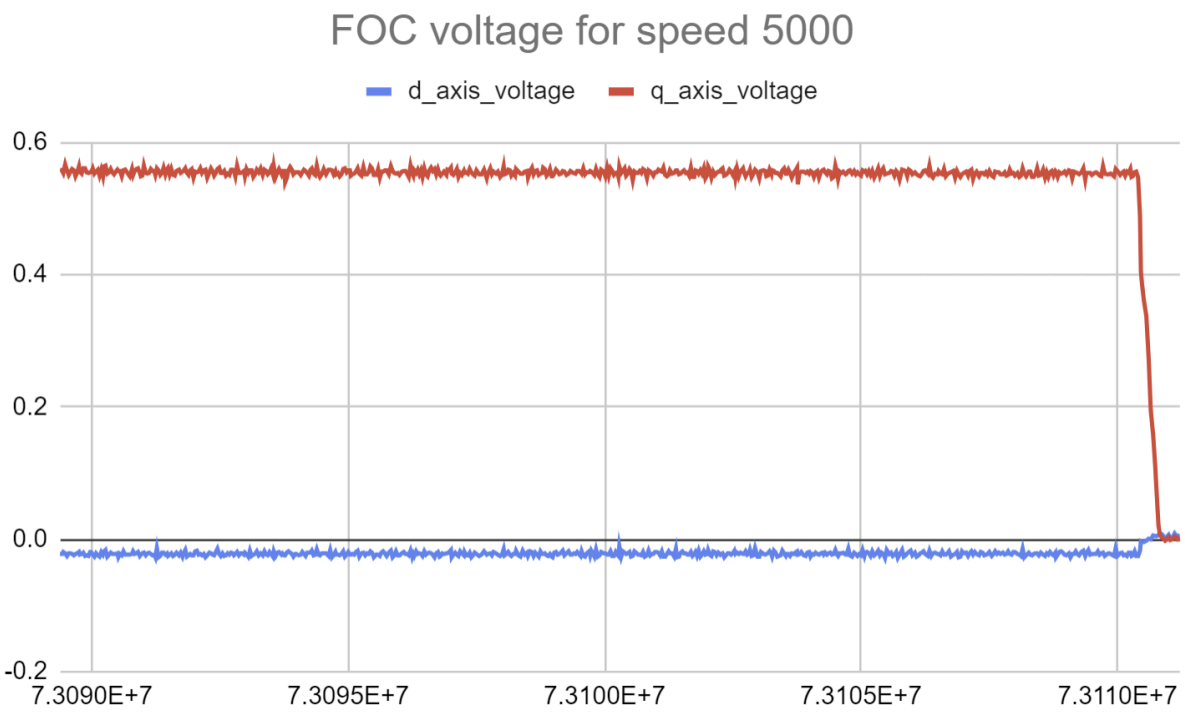
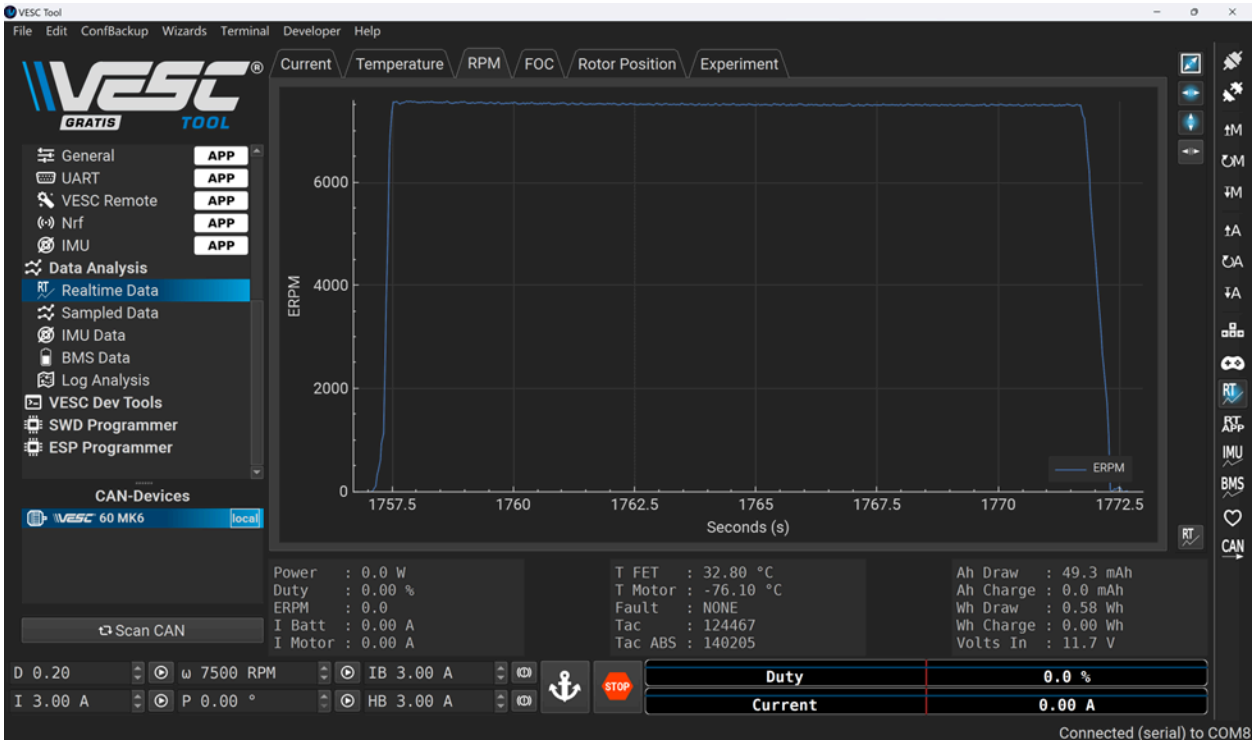
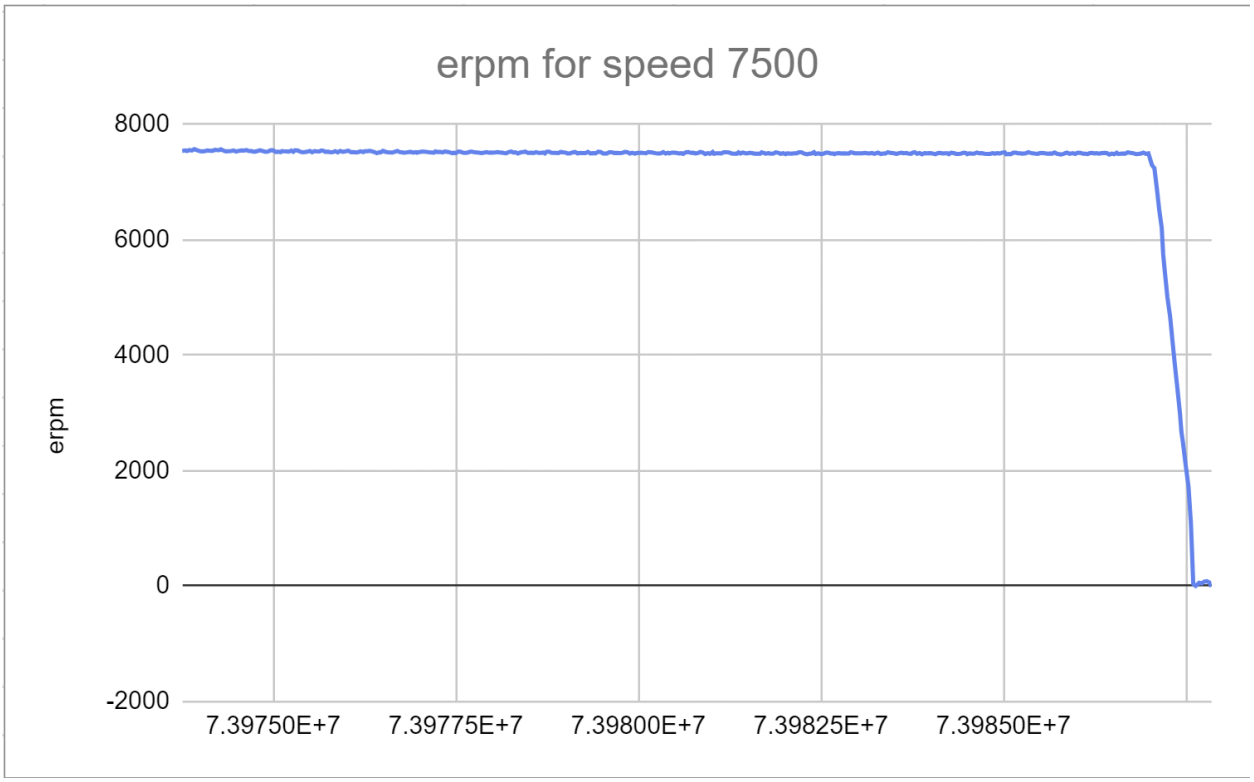
SWD Programmer
ESP Programmer
CAN-Devices
60 MK6 local
Scan CAN
Current
Voltage
Seconds (s)
D Current
Q Current
D Voltage
Q Voltage
Power : 0.0 W
Duty : -0.10 %
ERPM : -35.0
I Batt : 0.00 A
I Motor : 0.00 A
T FET : 32.60 °C
T Motor : -75.60 °C
Fault : NONE
Tac : 101812
Tac ABS : 117538
Ah Draw : 42.1 mAh
Ah Charge : 0.0 mAh
Wh Draw : 0.49 Wh
Wh Charge : 0.00 Wh
Volts In : 11.6 V
D 0.20
ω 5000 RPM
IB 3.00 A
I 3.00 A
P 0.00 °
HB 3.00 A
STOP
Duty -0.1 %
Current 0.00 A
Connected (serial) to COM8


FOC current for speed 5000
d_axis_current
q_axis_current
8
6
4
2
0
-2
7.3090E+7
7.3095E+7
7.3100E+7
7.3105E+7
7.3110E+7



speed 7500
RPM




erpm for speed 7500
8000
6000
4000
2000
0
-2000
erpm
7.39750E+7
7.39775E+7
7.39800E+7
7.39825E+7
7.39850E+7

FOC


VESC Tool
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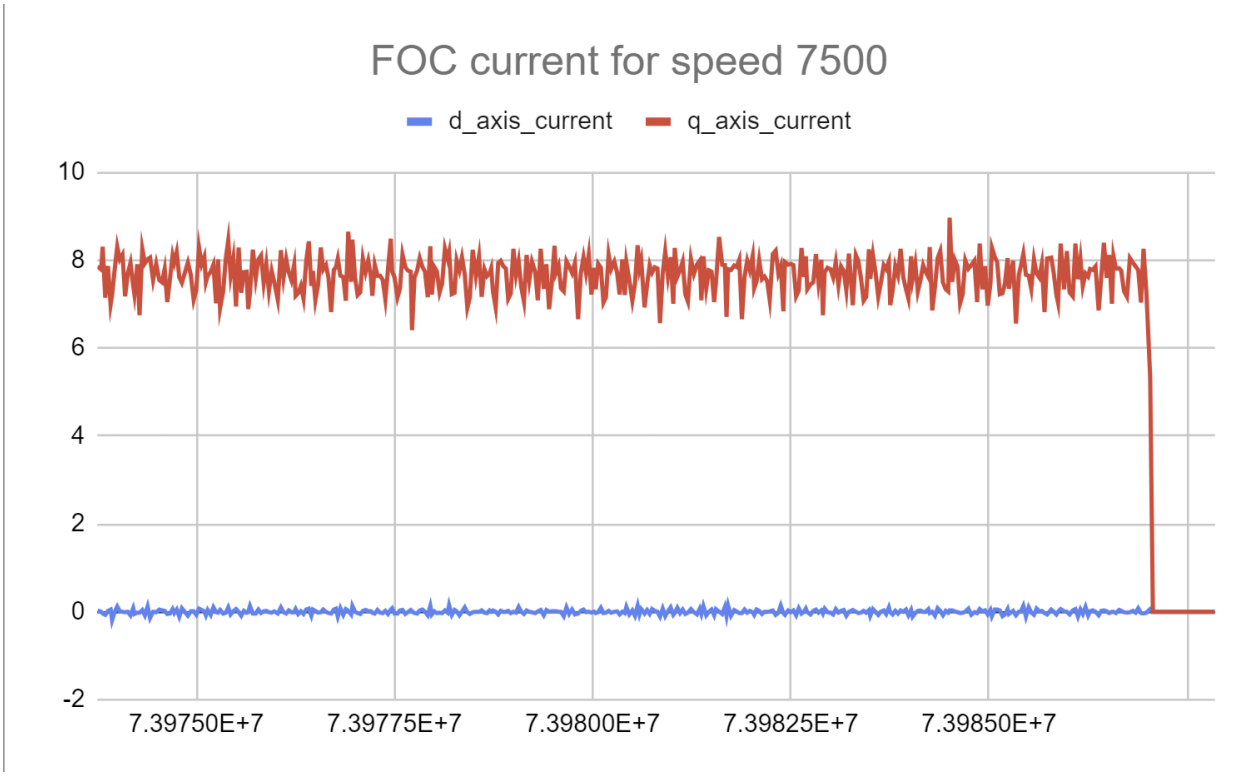
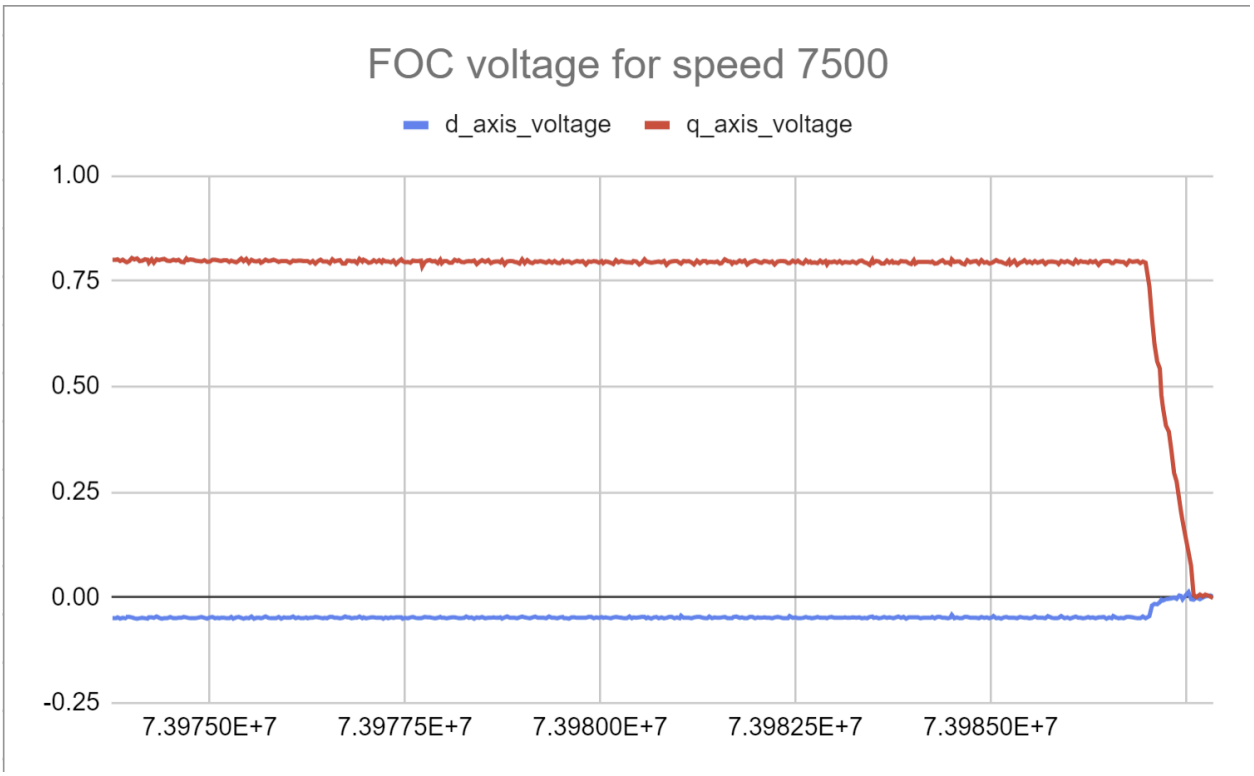
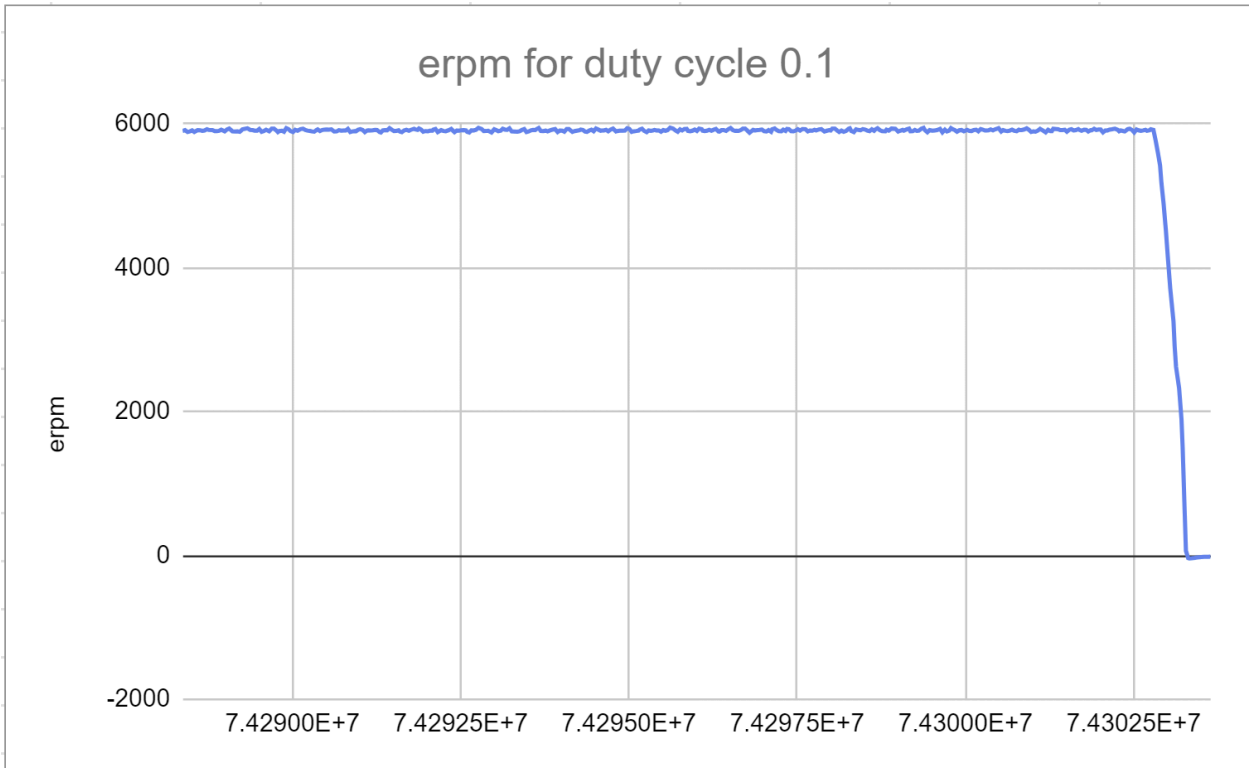
IMU Data
BMS Data
Log Analysis
VESC Dev Tools
SWD Programmer
ESP Programmer
CAN-Devices
60 MK6 local
Scan CAN
Current
Voltage
Seconds (s)
D Current
Q Current
D Voltage
Q Voltage
Power : 0.0 W
Duty : 1.60 %
ERPM : 1969.0
I Batt : 0.00 A
I Motor : 0.00 A
T FET : 32.80 °C
T Motor : -75.90 °C
Fault : NONE
Tac : 136180
Tac ABS : 151922
Ah Draw : 52.9 mAh
Ah Charge : 0.0 mAh
Wh Draw : 0.62 Wh
Wh Charge : 0.00 Wh
Volts In : 11.6 V
D 0.20
ω 7500 RPM
IB 3.00 A
I 3.00 A
P 0.00 °
HB 3.00 A
STOP
Duty 1.6 %
Current 0.00 A
Connected (serial) to COM8


FOC current for speed 7500
d_axis_current
q_axis_current
10
8
6
4
2
0
-2
7.39750E+7
7.39775E+7
7.39800E+7
7.39825E+7
7.39850E+7

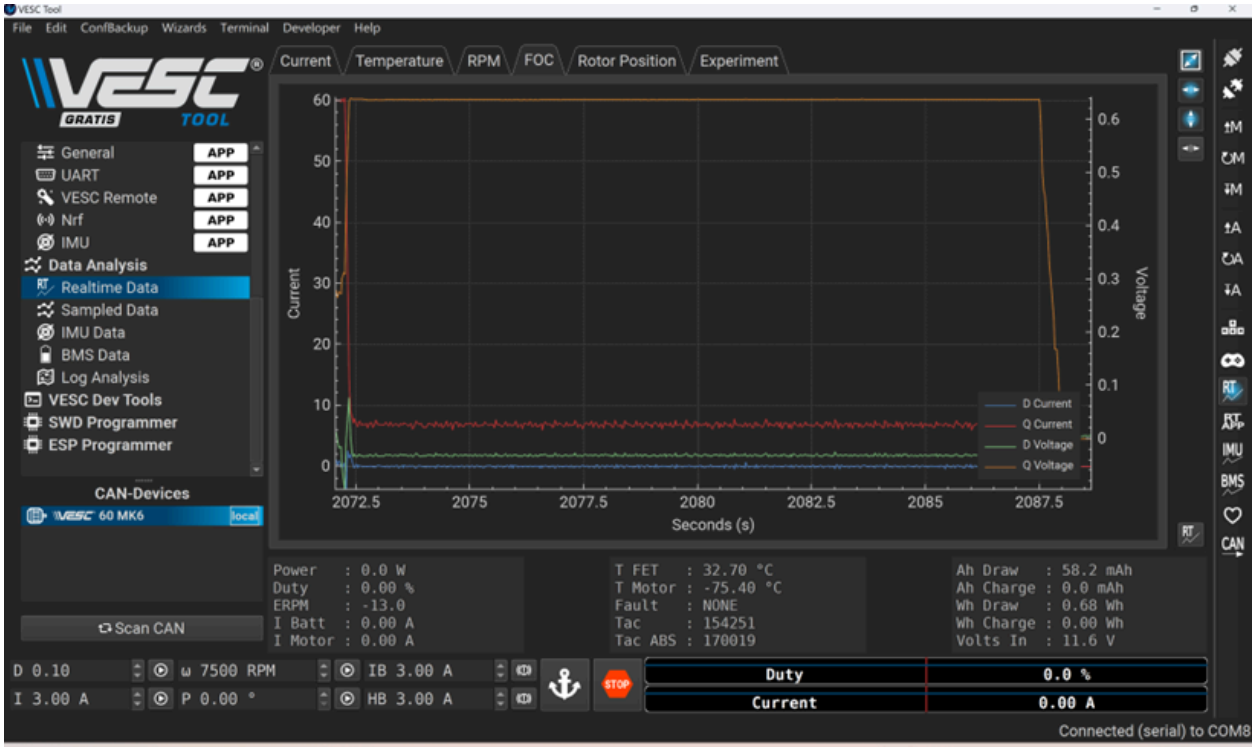

FOC voltage for speed 7500
d_axis_voltage
q_axis_voltage
1.00
0.75
0.50
0.25
0.00
-0.25
7.39750E+7
7.39775E+7
7.39800E+7
7.39825E+7
7.39850E+7

Question 4: Next test the motor operation with duty cycle input. Please maintain the duty cycle lower than 20%. (Recommended:start with a duty cycle of 0.10, then 0.15 and finally 0.2, Take a screenshot of Your RPM and FOC graphs. Log your data for each speed point and plot the graphs for RPM, FOC current (d- and q-axis currents), FOC voltage (d and q-axis voltages).

Duty cycle 0.1
RPM


erpm for duty cycle 0.1
6000
4000
2000
0
-2000
erpm
7.42900E+7
7.42925E+7
7.42950E+7
7.42975E+7
7.43000E+7
7.43025E+7

FOC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IMU APP
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Realtime Data
Sampled Data
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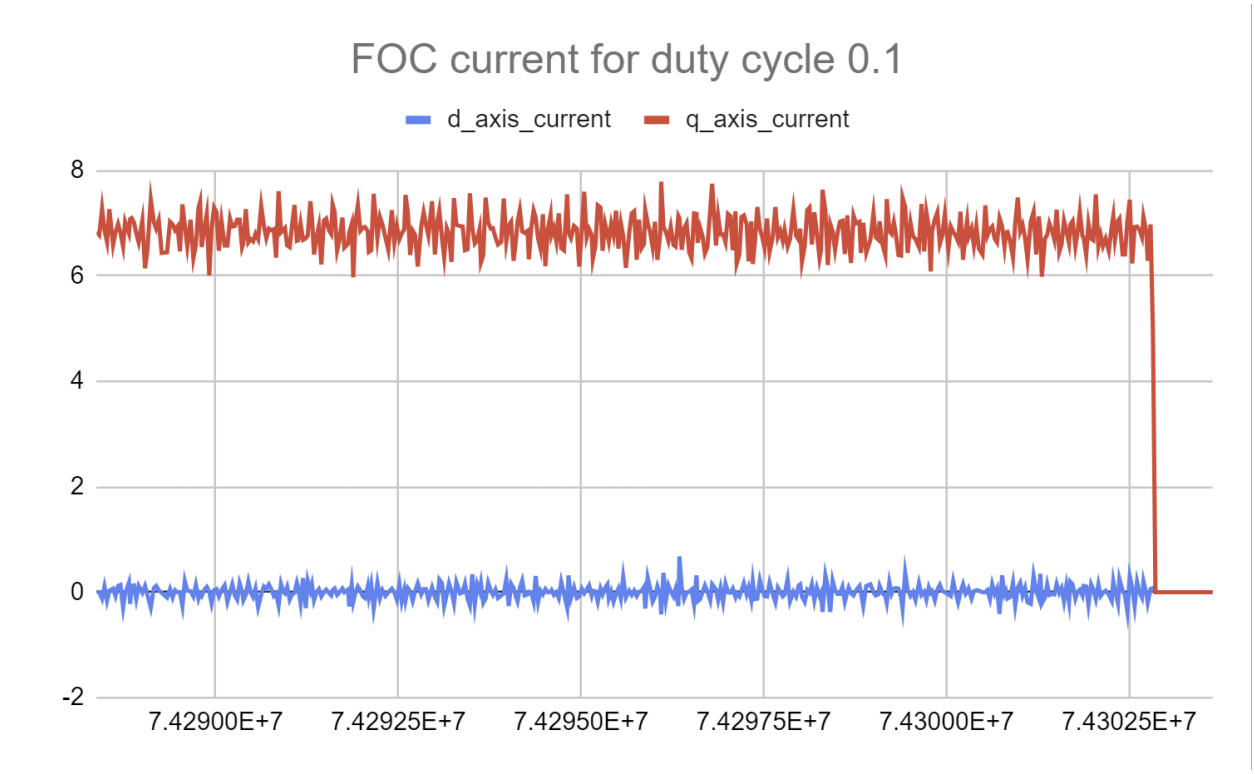
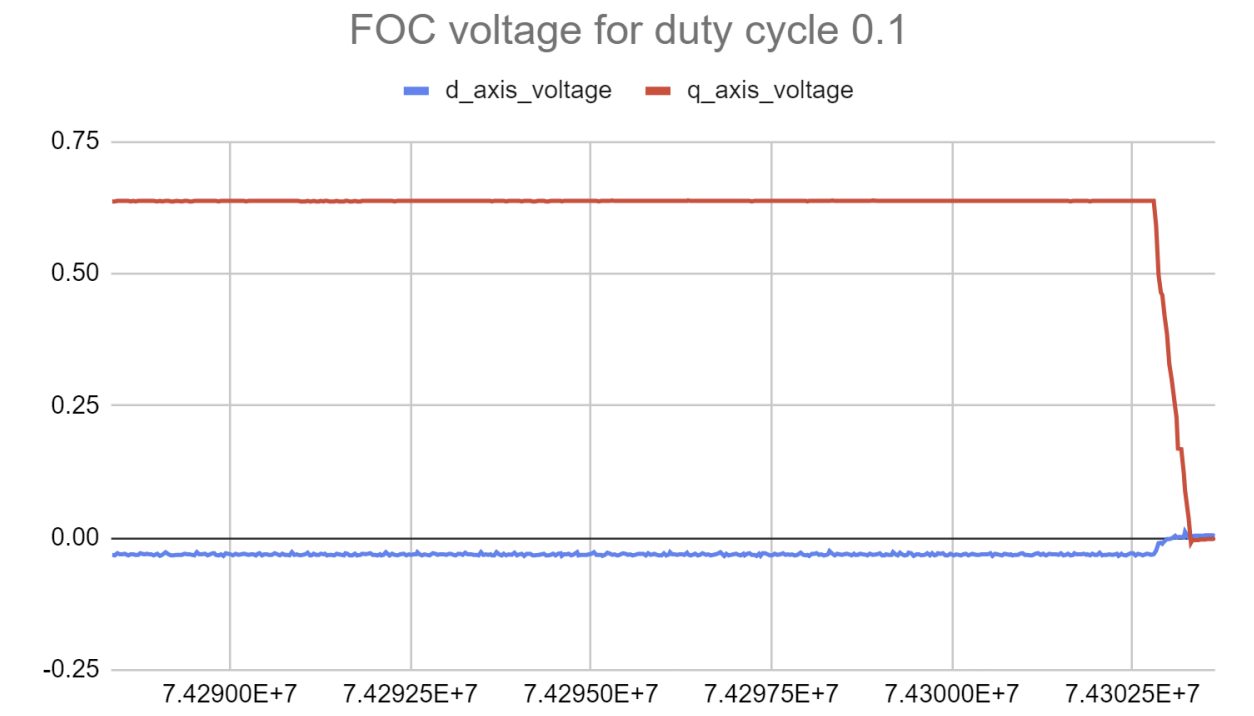
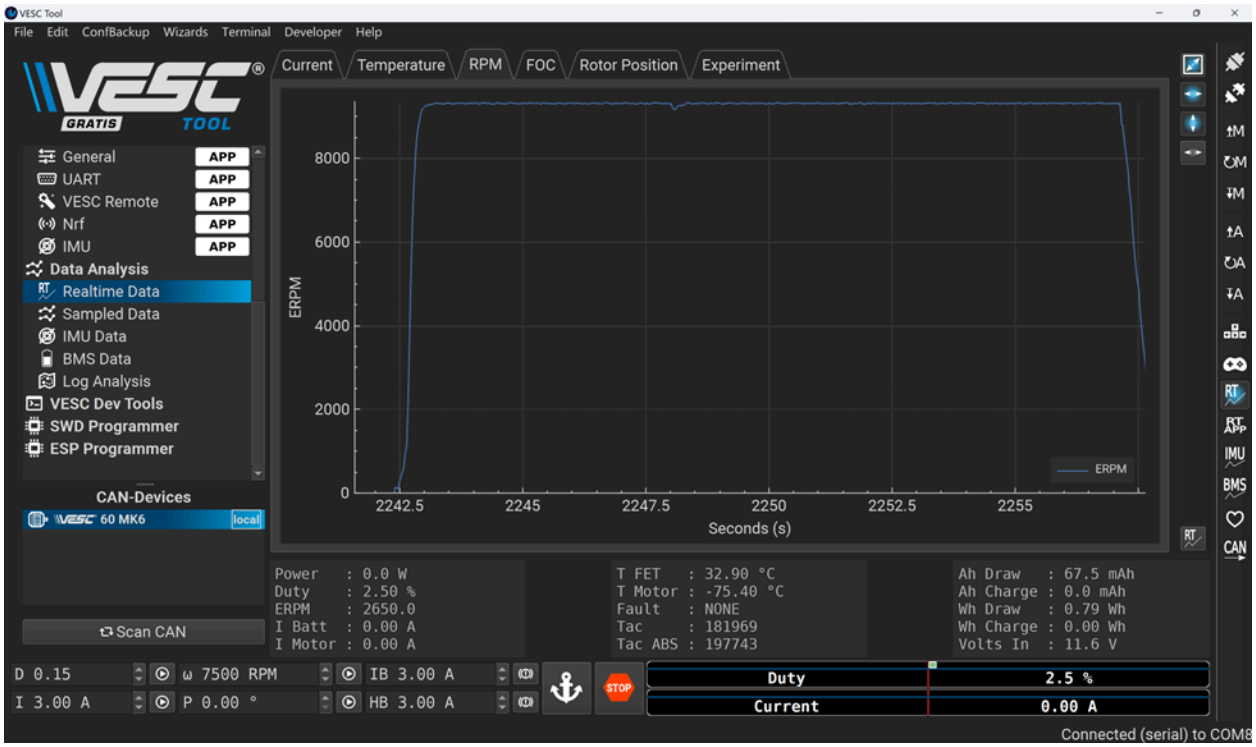
BMS Data
Log Analysis
VESC Dev Tools
SWD Programmer
ESP Programmer
CAN-Devices
Scan CAN
Current
Voltage
Seconds (s)
D Current
Q Current
D Voltage
Q Voltage
Power : 0.0 W
Duty : 0.00 %
ERPM : -13.0
I Batt : 0.00 A
I Motor : 0.00 A
T FET : 32.70 °C
T Motor : -75.40 °C
Fault : NONE
Tac : 154251
Tac ABS : 170019
Ah Draw : 58.2 mAh
Ah Charge : 0.0 mAh
Wh Draw : 0.68 Wh
Wh Charge : 0.00 Wh
Volts In : 11.6 V
Duty 0.0 %
Current 0.00 A
Connected (serial) to COM8





Duty cycle 0.15

RPM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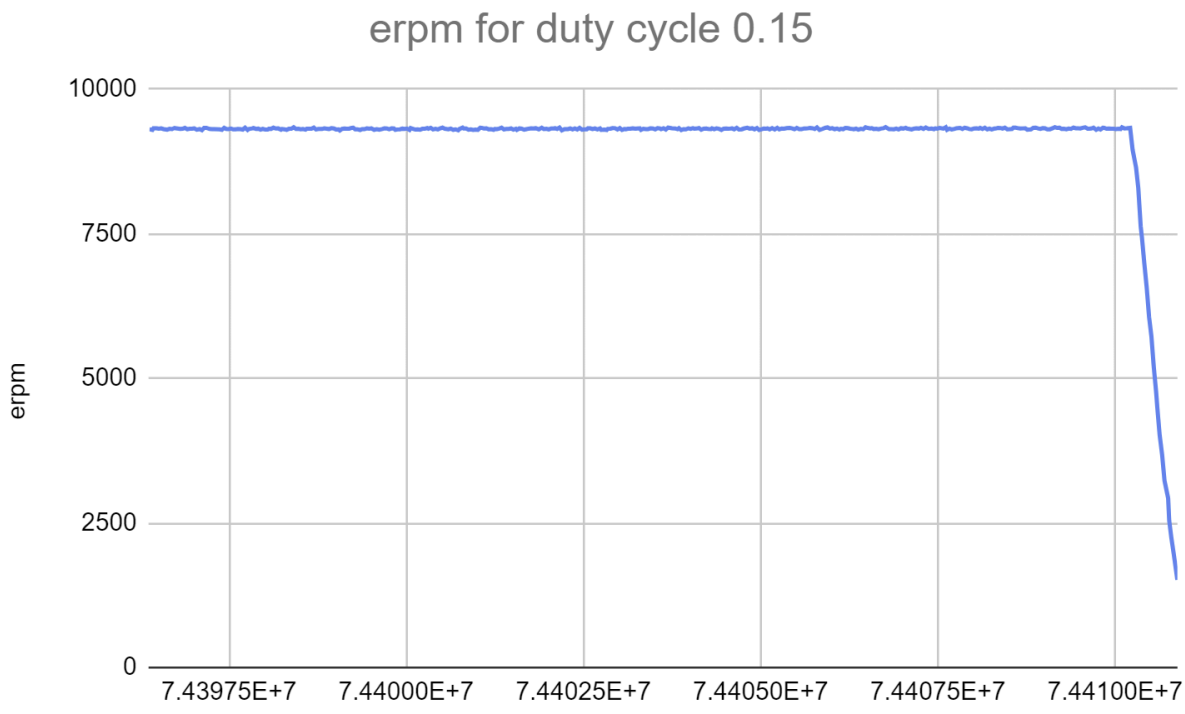
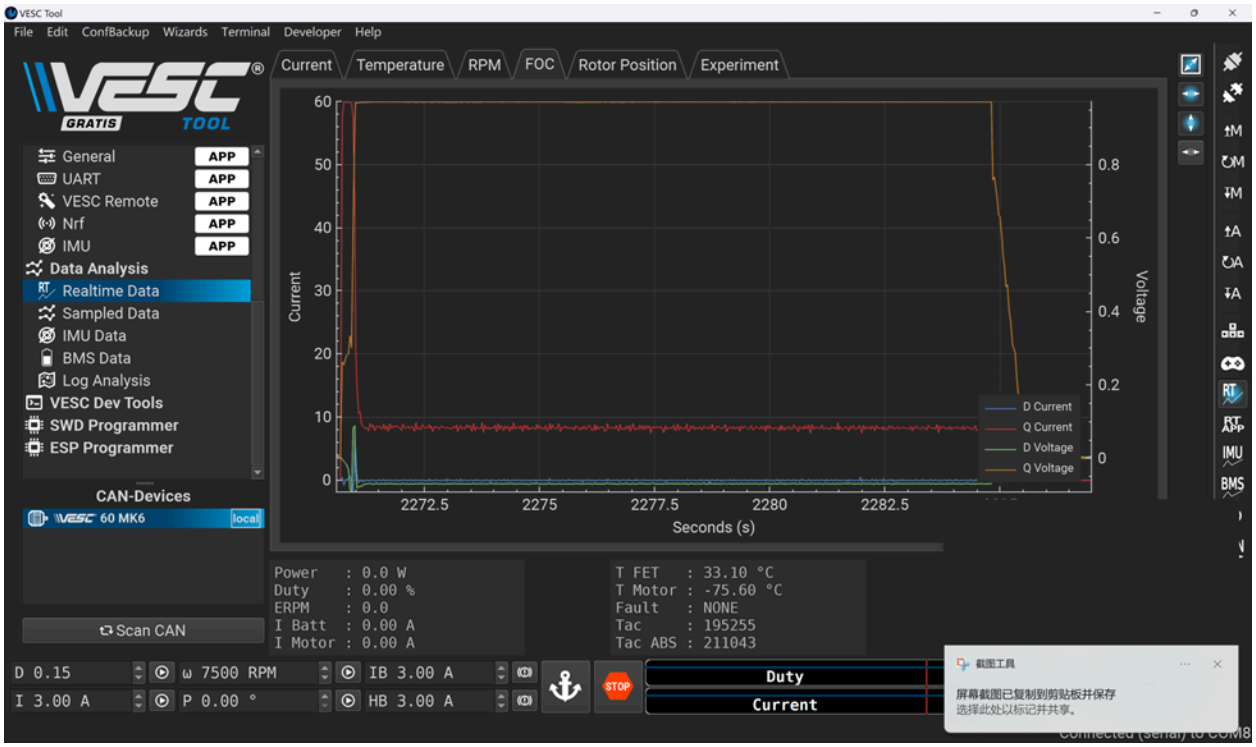
ESP Programmer
CAN-Devices
60 MK6 local
Scan CAN
ERPM
8000
6000
4000
2000
0
2242.5
2245
2247.5
2250
2252.5
2255
Seconds (s)
Power : 0.0 W
Duty : 2.50 %
ERPM : 2650.0
I Batt : 0.00 A
I Motor : 0.00 A
T FET : 32.90 °C
T Motor : -75.40 °C
Fault : NONE
Tac : 181969
Tac ABS : 197743
Ah Draw : 67.5 mAh
Ah Charge : 0.0 mAh
Wh Draw : 0.79 Wh
Wh Charge : 0.00 Wh
Volts In : 11.6 V
D 0.15
ω 7500 RPM
IB 3.00 A
I 3.00 A
P 0.00 °
HB 3.00 A
STOP
Duty 2.5 %
Current 0.00 A
Connected (serial) to COM8


erpm for duty cycle 0.15
erpm
10000
7500
5000
2500
0
7.43975E+7
7.44000E+7
7.44025E+7
7.44050E+7
7.44075E+7
7.44100E+7

FOC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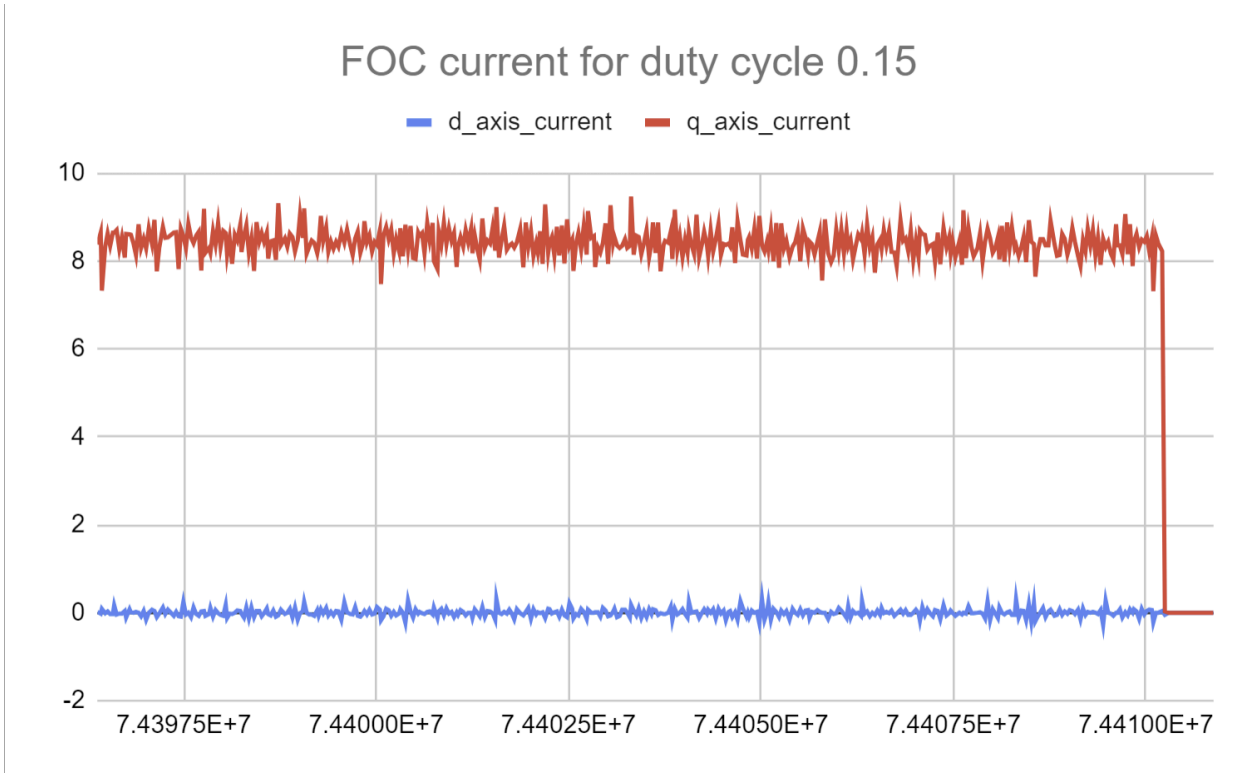
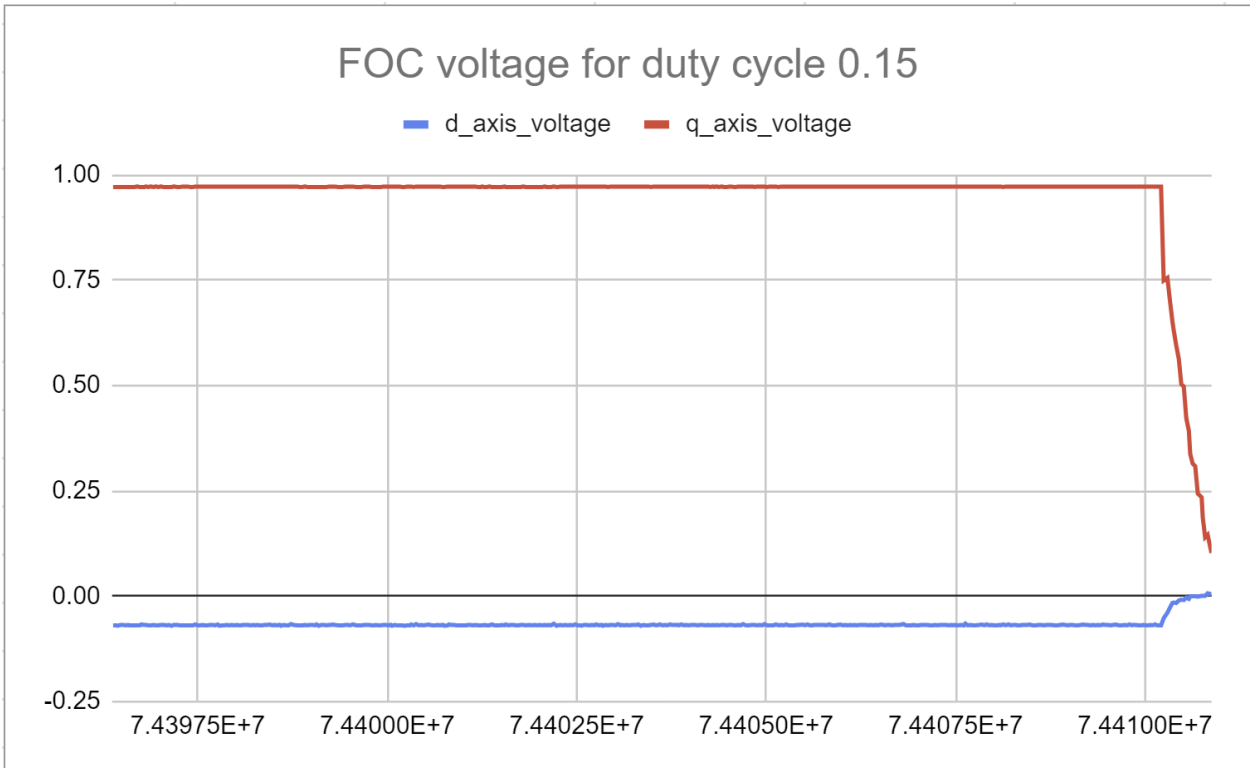
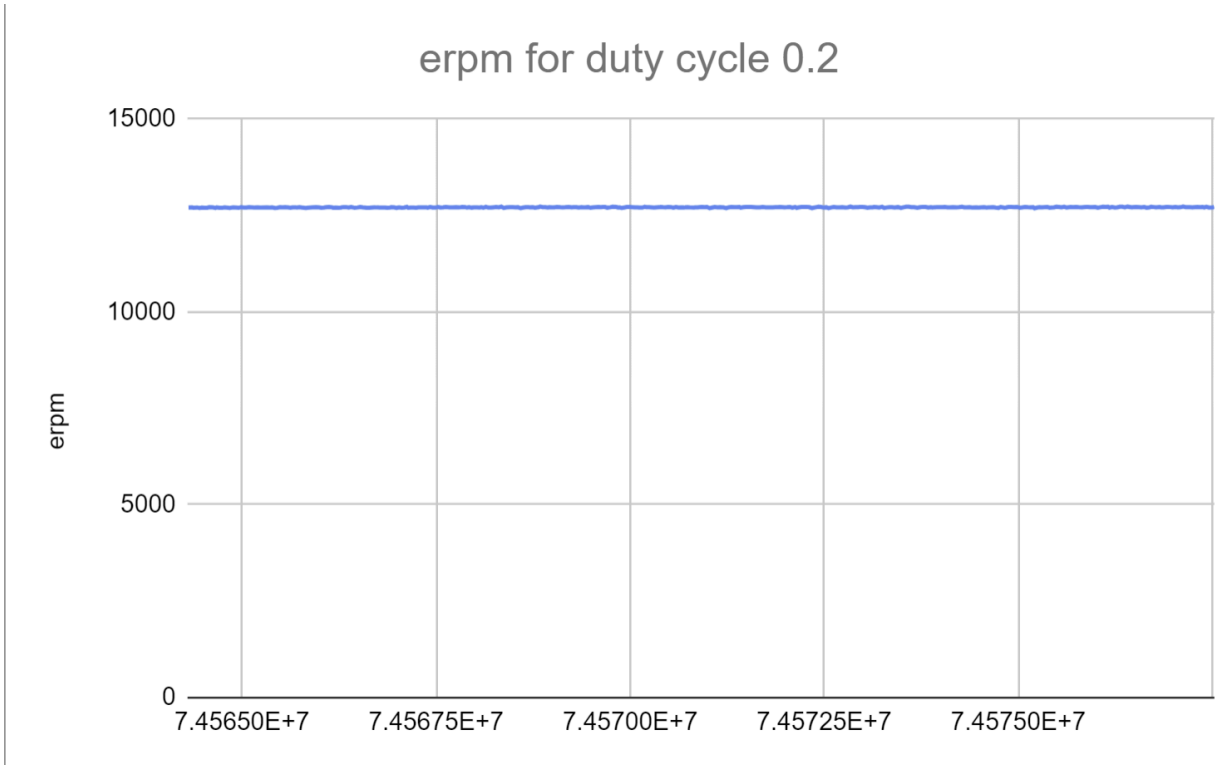
ESP Programmer
CAN-Devices
60 MK6 local
Scan CAN
Current
Voltage
Seconds (s)
D Current
Q Current
D Voltage
Q Voltage
Power : 0.0 W
Duty : 0.00 %
ERPM : 0.0
I Batt : 0.00 A
I Motor : 0.00 A
T FET : 33.10 °C
T Motor : -75.60 °C
Fault : NONE
Tac : 195255
Tac ABS : 211043
D 0.15
ω 7500 RPM
IB 3.00 A
I 3.00 A
P 0.00 °
HB 3.00 A
STOP
Duty
Current
屏幕截图已复制到剪贴板并保存
选择此处以标记并共享。


FOC current for duty cycle 0.15
d_axis_current
q_axis_current
10
8
6
4
2
0
-2
7.43975E+7
7.44000E+7
7.44025E+7
7.44050E+7
7.44075E+7
7.44100E+7



Duty cycle 0.2
RPM


erpm for duty cycle 0.2
15000
10000
5000
0
erpm
7.45650E+7
7.45675E+7
7.45700E+7
7.45725E+7
7.45750E+7

FOC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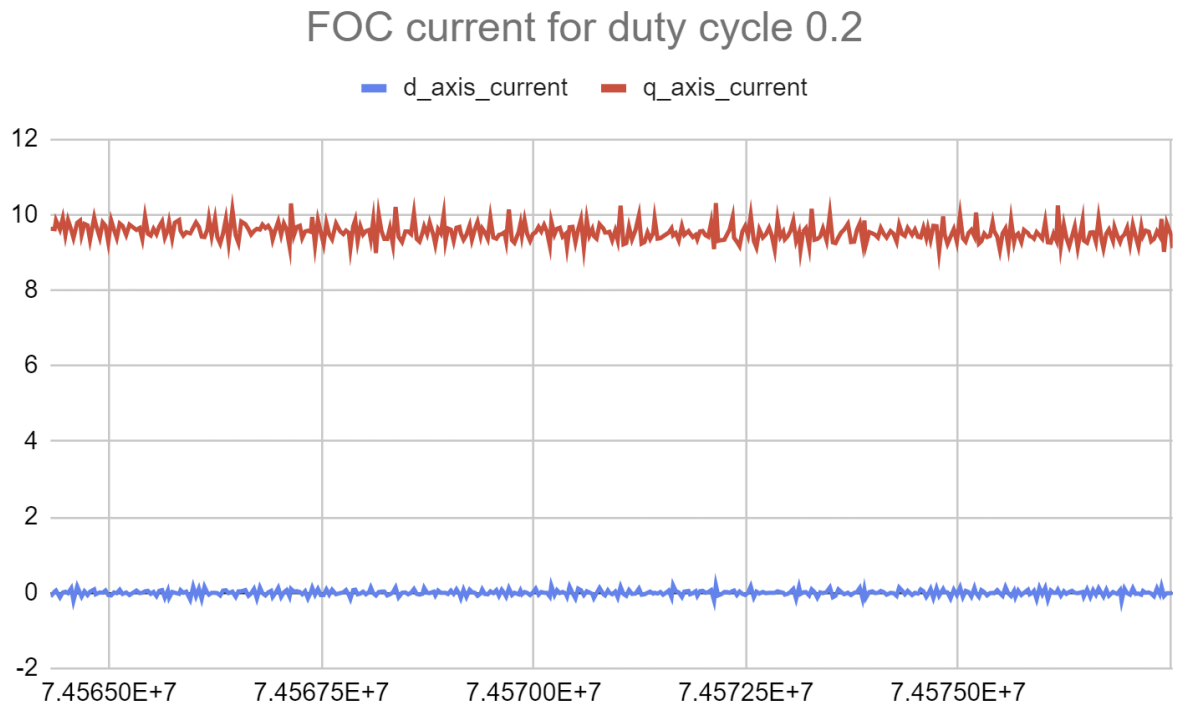
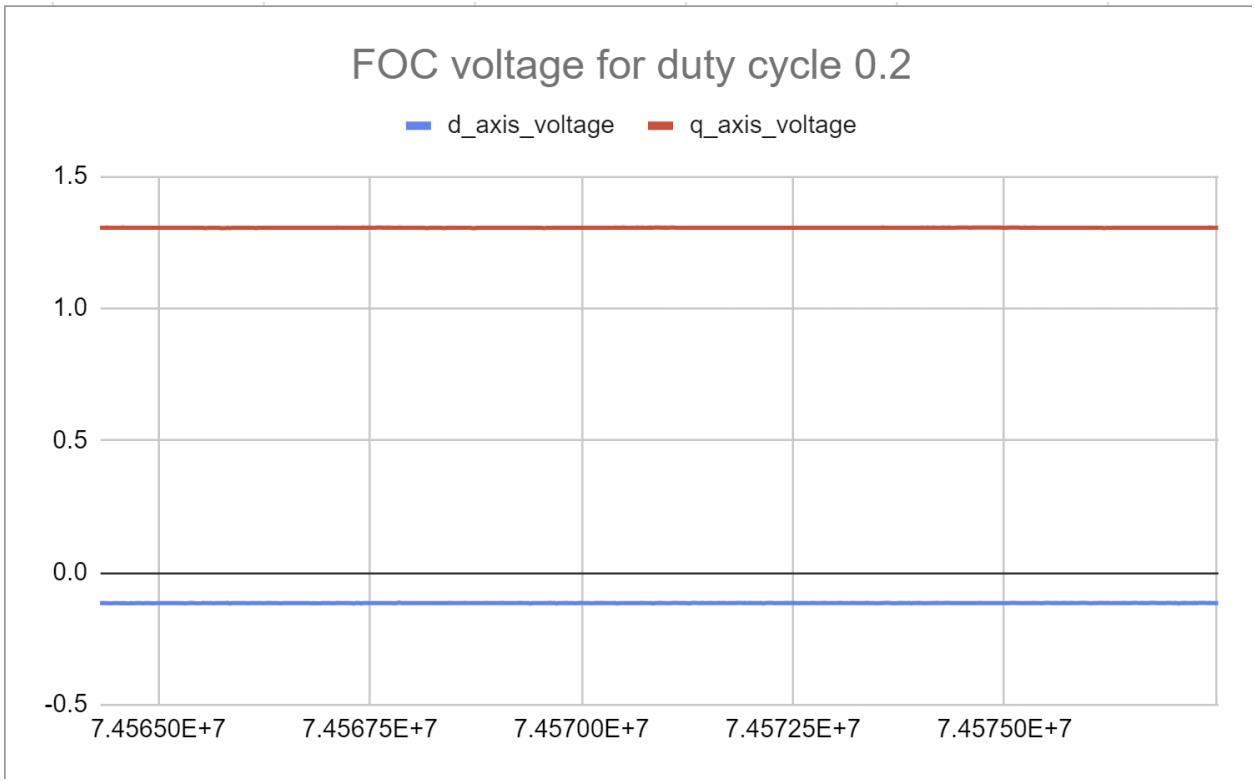
SWD Programmer
ESP Programmer
CAN-Devices
60 MK6 local
Scan CAN
Current
Voltage
Seconds (s)
D Current
Q Current
D Voltage
Q Voltage
Power : 0.0 W
Duty : 7.50 %
ERPM : 6003.0
I Batt : 0.00 A
I Motor : 0.00 A
T FET : 33.60 °C
T Motor : -75.70 °C
Fault : NONE
Tac : 233477
Tac ABS : 249269
Ah Draw : 86.1 mAh
Ah Charge : 0.0 mAh
Wh Draw : 1.01 Wh
Wh Charge : 0.00 Wh
Volts In : 11.6 V
D 0.20
ω 7500 RPM
IB 3.00 A
I 3.00 A
P 0.00 °
HB 3.00 A
STOP
Duty 7.5 %
Current 0.00 A
Connected (serial) to COM8


FOC current for duty cycle 0.2
d_axis_current
q_axis_current
12
10
8
6
4
2
0
-2
7.45650E+7
7.45675E+7
7.45700E+7
7.45725E+7
7.45750E+7


FOC voltage for duty cycle 0.2
d_axis_voltage
q_axis_voltage
1.5
1.0
0.5
0.0
-0.5
7.45650E+7
7.45675E+7
7.45700E+7
7.45725E+7
7.45750E+7

Question 5: What difference do you observe between the operations with the speed command and duty cycle command? Explain the difference using the real-time voltage, current, and speed waveforms.

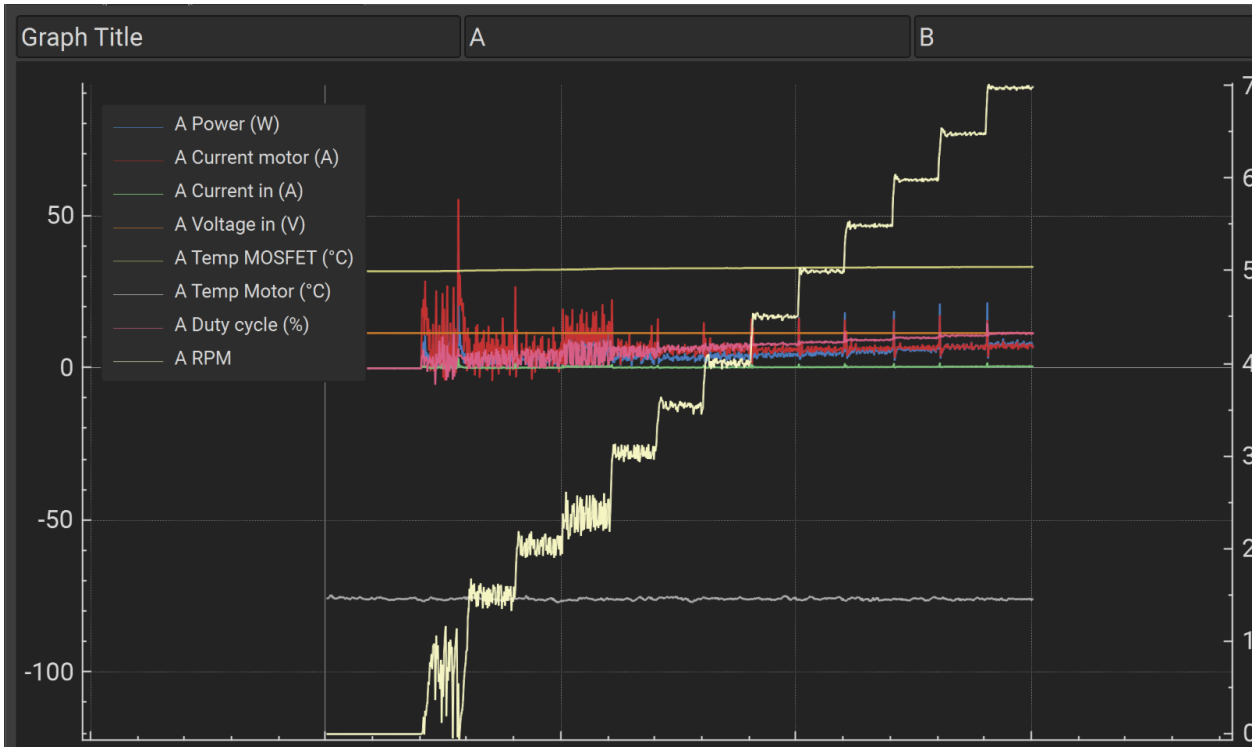
Duty cycle instructions are more efficient than speed instructions because an increase in duty cycle causes a large and rapid increase in ERPM, while speed instructions only reach that speed value. However, the speed command can reach a specific speed range which is more accurate than the duty cycle command. Additionally, increasing duty cycle and speed increases voltage, but an increase in duty cycle changes the voltage more directly. Essentially, the duty cycle command changes the voltage percentage relative to the equivalent voltage.

Question 6: What is the definition of the d and q-axis currents? Why is the d-axis current always zero? Please check your lecture notes.

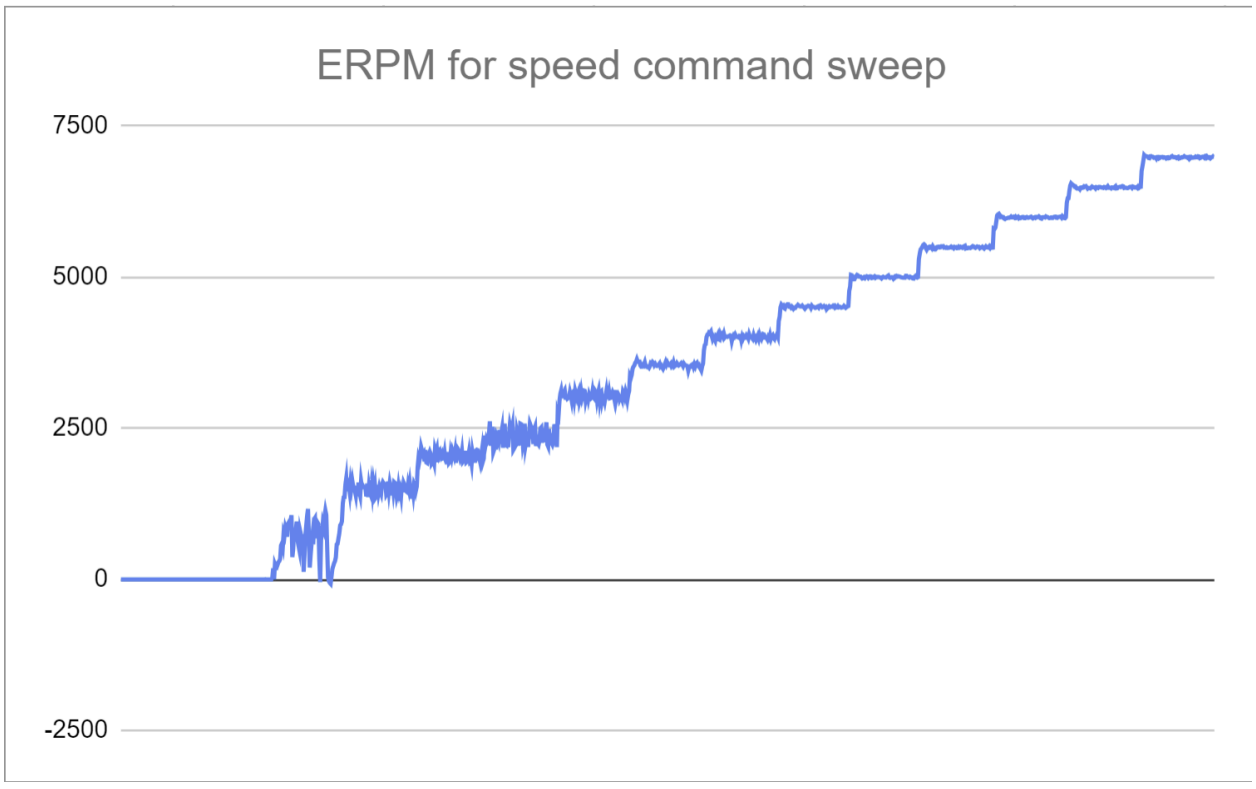
The d-axis current (id) is the excitation current and is used to control the magnetic flux of the synchronous motor. The q-axis current (iq) is the torque-producing current that is orthogonal to the d-axis current and controls the motor's torque. The d-axis current is in the same direction as the magnetic field. When the d-axis current needs to be accelerated, it also means that greater torque is needed to accelerate. However, in order to simplify the control method at high speed, the d-axis current in the BLDC motor control system is set to zero. When the d-axis current is zero, the motor operates as a constant torque machine and does not require much torque to maintain high-speed motion.

Question 7: Record the experiment results in a .csv file and plot them for your report. Explore how you can log the experiment with Realtime Data feature in the VESC Tool. Attach a screenshot of your plot tab in your report. Attach two graphs from your .csv file: one for RPM and the other one for q-axis current.

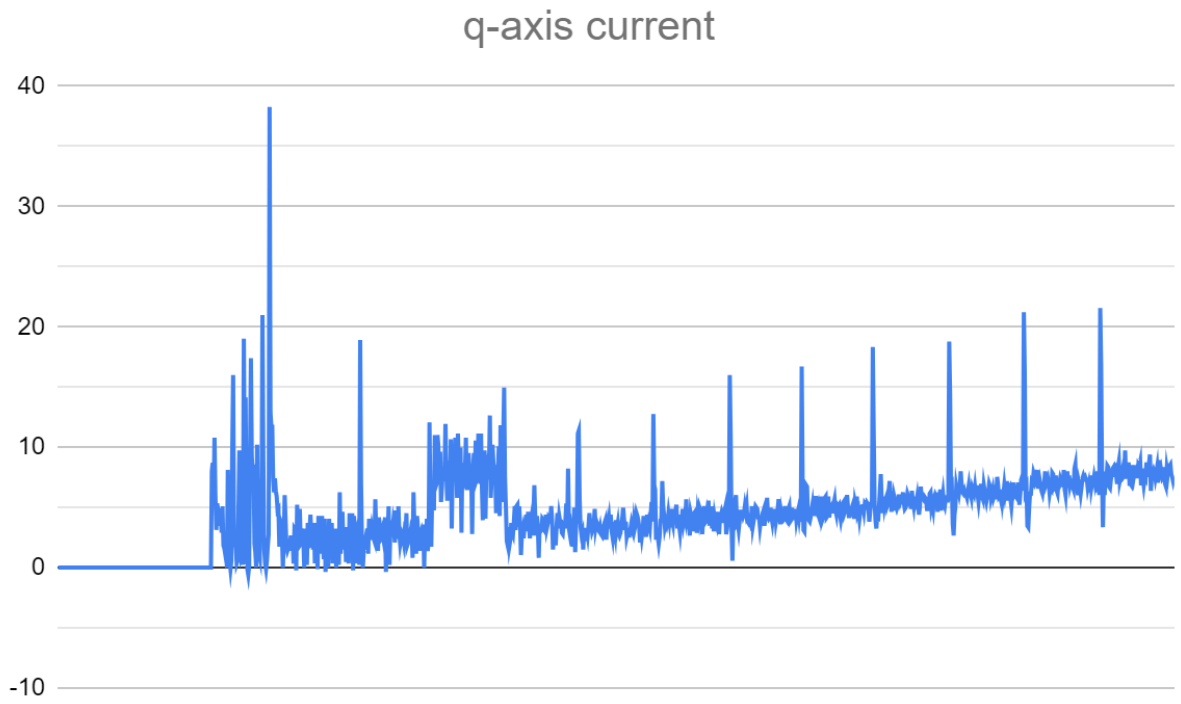
The plot:


Graph Title
A
B
A Power (W)
A Current motor (A)
A Current in (A)
A Voltage in (V)
A Temp MOSFET (°C)
A Temp Motor (°C)
A Duty cycle (%)
A RPM
50
0
-50
-100

RPM

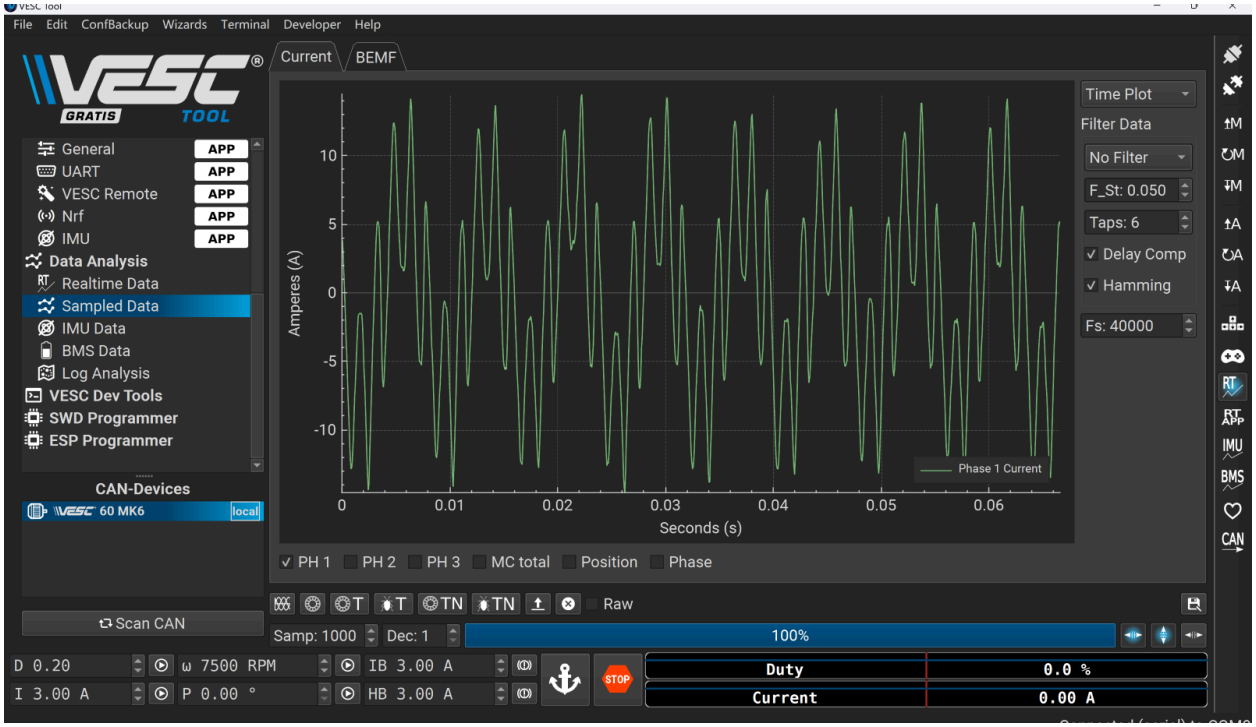

ERPM for speed command sweep
7500
5000
2500
0
-2500

q-axis current

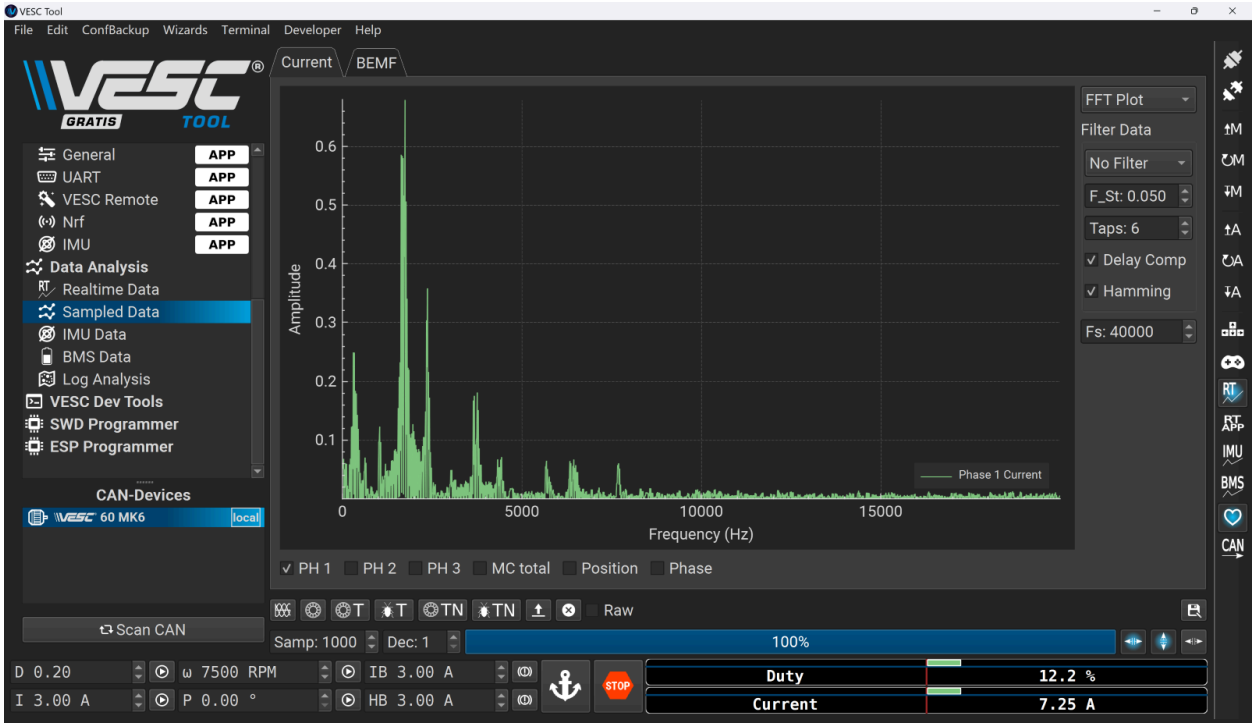


Question 8: Explore the Sampled Data feature in the VESC Tool. For constant speed operation in FOC mode, record the sampled phase current waveforms. Explore the FFT option in the VESC tool and apply it to the phase current measurements. Report the results by applying the speed command and then click on Sample Now button. Attach a screenshot of your FFT plot in your report.

The phase current for an RPM of 7500 (in time domain):



The FFT for the phase current:



Question 9: What is an FFT plot? Why is an FFT plot applied to the phase current measurements important when analyzing the behavior of a motor?

A FFT plot is the fourier transform of the signal, and it provides details about the harmonics and their magnitudes of the signal. Phase current is the current flowing through one phase of the motor. When an FFT plot is applied to measure phase current, it will show the different frequencies present in the phase currents, which can reveal whether there are unnecessary harmonics or noise that may affect motor performance. This adjusts the motor to run more efficiently and avoid power losses or inefficient frequencies. The presence of unexpected harmonics can also be used to identify any faults with the motor and prevent early failure.