CTR Electronics Motor Testing Report

Overview

Utilizing an in-house dyno, CTR Electronics empirically tests motor performance both during our iterative product development process, and also to ensure quality assurance during the pre-production and manufacturing phases of a project.

Our process has been peer reviewed by “motor experts” from both inside the FRC community as well as industry. This same process has been used successfully on several past motor design projects for FRC and OEM customers. In addition we validated our methodologies against existing motors with known “real-world” performance data.

Test Equipment

- Torque Sensor (accuracy to <1%, up to date calibration)
- Velocity Sensor (accuracy to <1%)
- 12V Regulated Power Supply with sense leads for the motor under test
- Supply Side Ammeter
- Supply Side Voltmeter
- Braking Motor System (provides controlled braking torque)
- Isolated power source for Braking Motor System
- Strategy to ensure consistent electrical and mechanical efficiency outside the motor under test:
    - Custom mounting brackets, when needed
    - Proper coupling solution to ensure concentricity/coaxiality
    - Proper power connection strategy
    - Comparable cable lengths on all test motors
- Redundant markers to ensure no slip anywhere in the rotor/connection stackup. (paintmarks)
- CTR Electronics in-house Dynamometer Software built using Phoenix 6.
    - Data collection via CAN bus.

Motor Performance Curve Testing

Test Setup

Mechanically & Electrically Install the New Motor into Text Fixture.

Confirm torque sensor tare is accurate. This involves a procedure that profiles the tare point and confirms it is near zero. This is also done periodically to confirm tare has not walked (which it doesn't).

Initial Test Run

Utilizing the dynamometer software, drive both the test motor and braking motor in the same direction at 100% output. (Effectively applies little to no brake).

Confirm redundant markers are present and aligned at all torque couplings and potential "slip" locations.

Motors under test are run with no current limit in place, under 100% commanded output with no in-line circuit breaker or fuse.

Motors under test do not receive any active “thermal assistance” such as an outside fan, external heat-sink or other method.

Utilizing the dynamometer software, increase the brake amount marginally. Pause, and wait a period of time before taking readings. This eliminates many sources of error including error stemming from the rotor inertia.

Repeat sampling at chosen intervals until load exceeds 1Nm (for FRC size motors this usually terminates around 65 Amps).

For each sample, the dynamometer software reports/logs: torque, supply current, supply voltage, velocity, power, and efficiency.

Test Validation

Confirm the redundant markers are still aligned and no slip occurred during the test run.

Review Data:
-Validate the supply voltage was constant and sufficient (Typical error < 0.3%)
-Confirm Torque vs Current linear regression: R^2 > 0.999
-Confirm Current vs Velocity linear regression: R^2 > 0.996
-Confirm Torque vs Velocity linear regression: R^2 > 0.996
-Check for outlier data points in current vs velocity, torque vs velocity, torque vs current, velocity vs efficiency.

Repetition for Data Repeatability

Wait in between tests to ensure all components properly return to ambient temperature.

Repeat the procedure at least three times.

Confirm values are comparable across three runs.

Repeat test procedure with FOC Enable/Disable Flipped

Repeat with additional motor sample(s) as desired.

Data Reporting / Extrapolation

At the end of tests, we should have at least 12 test run data sets:
Motor 1 - Test Run 1 - Trapezoidal
Motor 1 - Test Run 2 - Trapezoidal

Motor 1 - Test Run 3 - Trapezoidal
Motor 1 - Test Run 1 - FOC
Motor 1 - Test Run 2 - FOC
Motor 1 - Test Run 3 - FOC
Motor 2 - Test Run 1 - Trapezoidal
Motor 2 - Test Run 2 - Trapezoidal
Motor 2 - Test Run 3 - Trapezoidal
Motor 2 - Test Run 1 - FOC
Motor 2 - Test Run 2 - FOC
Motor 2 - Test Run 3 - FOC

For motor solutions that lack the FOC feature, three trials are sufficient.

At this point we now have the extrapolated linear regressions to generate torque and current as a function of velocity. We also have linear regressions to generate torque and velocity as a function of current.

Once we've identified the key performance numbers we are able to generate the full motor curves as a function of velocity.

Motors Tested

NEO Motor v1.0 & Spark Max
NEO Vortex & SPARK Flex
Falcon 500
Falcon 500 (FOC)
Kraken X60
Kraken X60 (FOC)

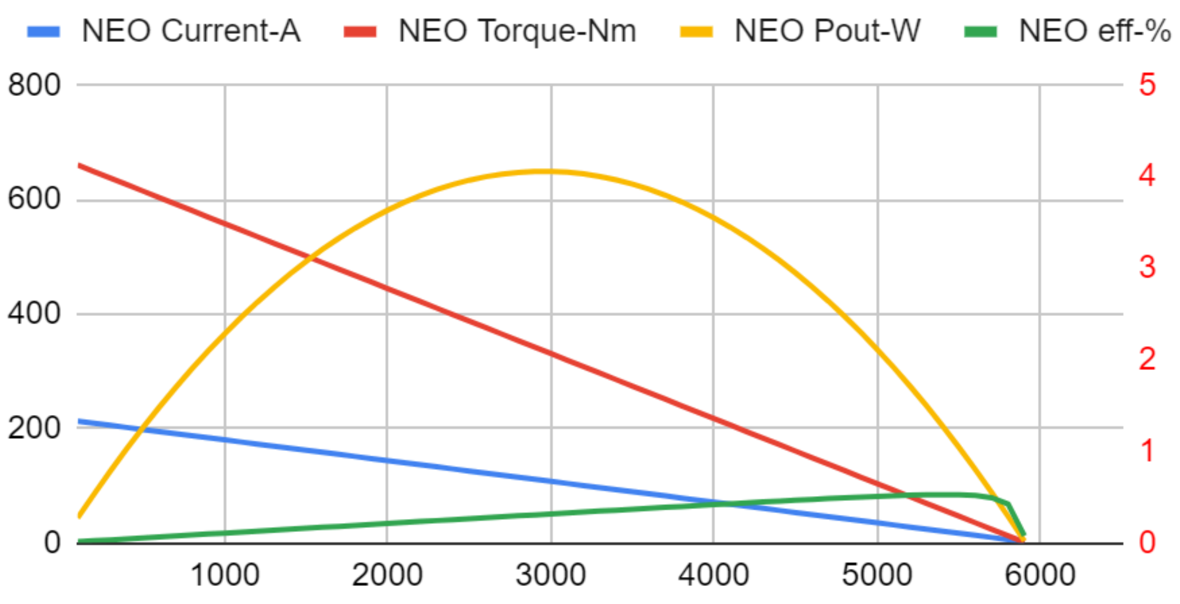
Power Harness

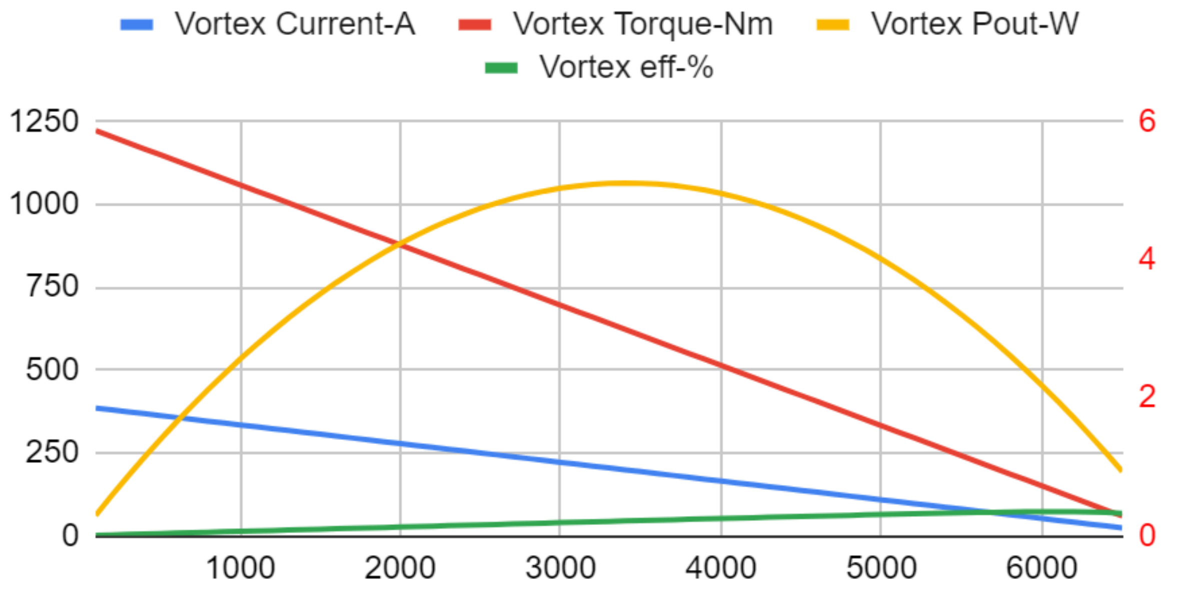
All integrated motor testing uses the stock cabling that arrives with the product. Power/ground leads cut to a common length of 9.75 in (with the exception of the Spark Max, which was cut to a smaller length of 3 in, NEO leads left at their original lead lengths).

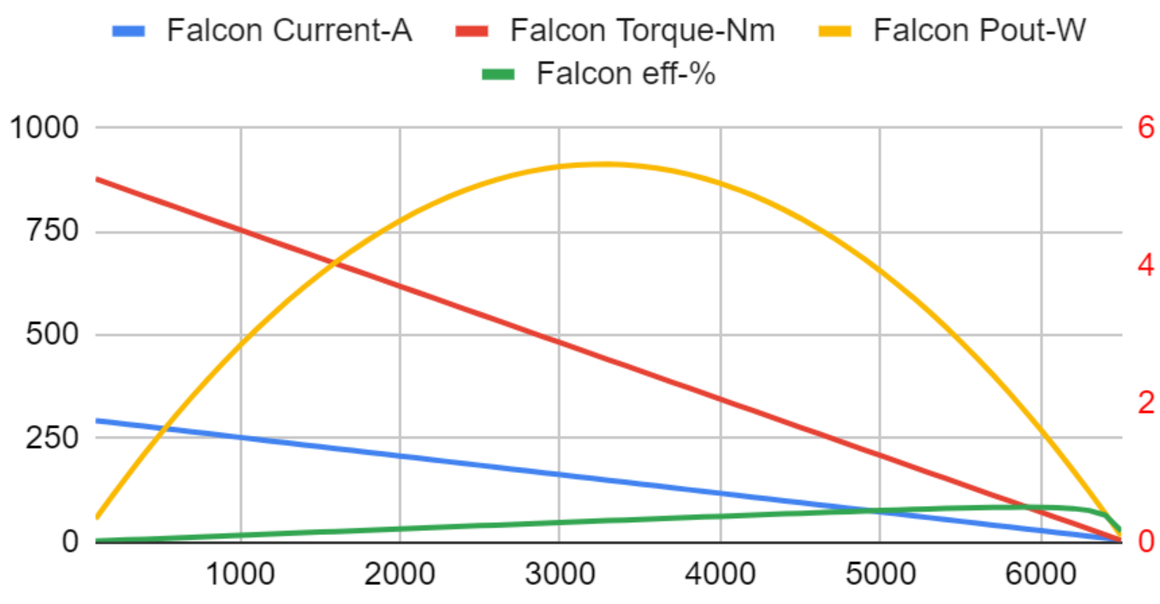
Software & Control

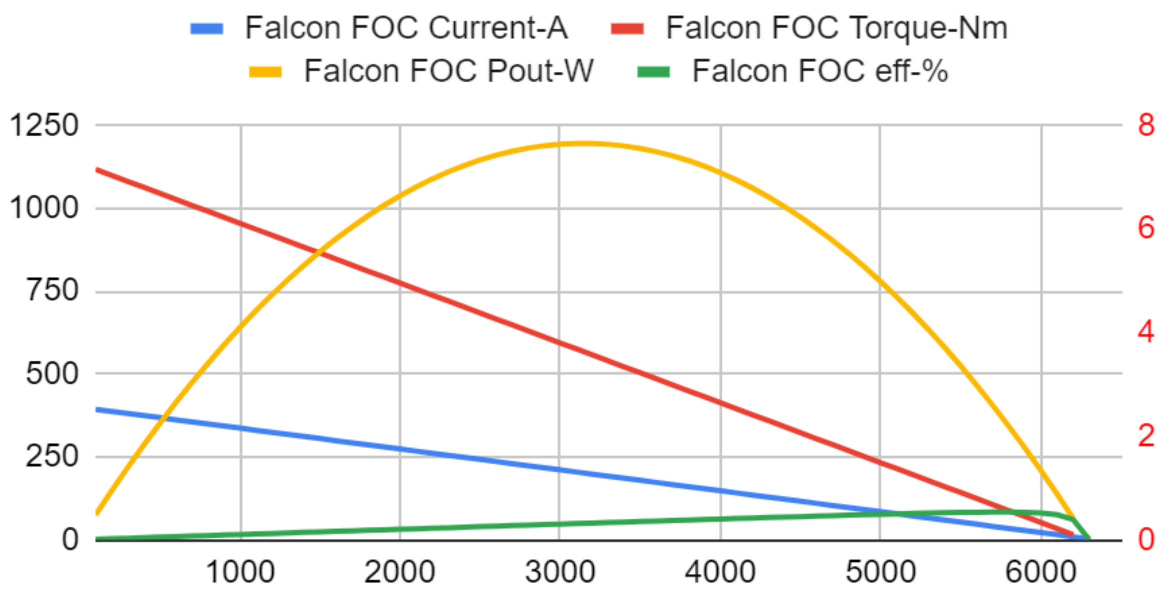
All motor controllers updated to the latest firmware as of Jan 8, 2024.
All motor controllers had current limiting disabled, and were commanded using 100% duty-cycle over CAN bus.

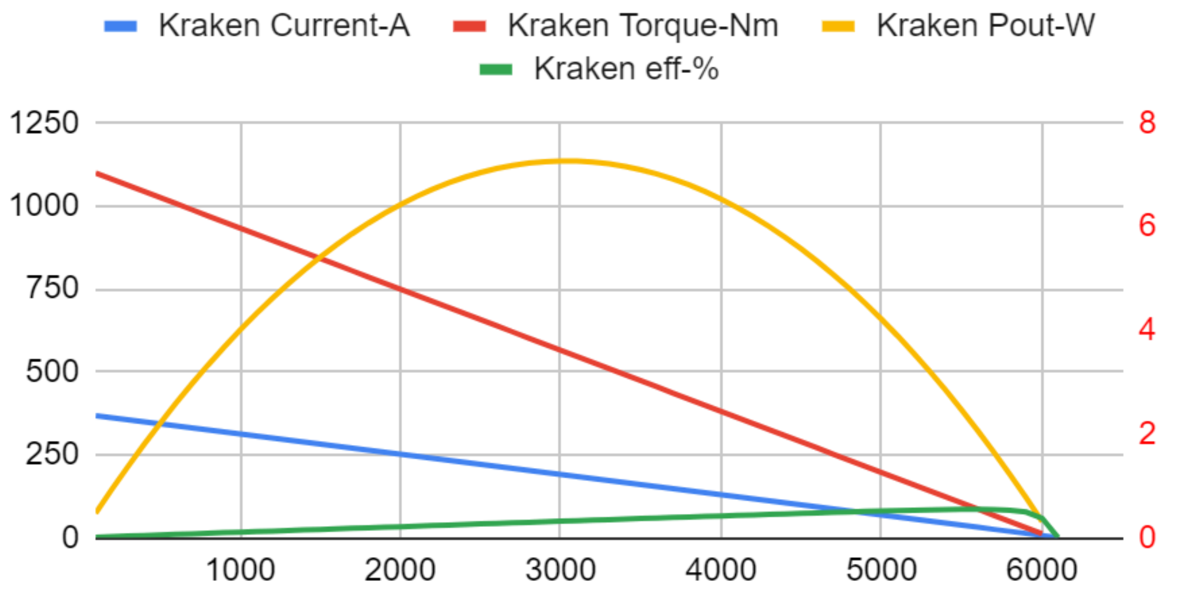
Motor Curves

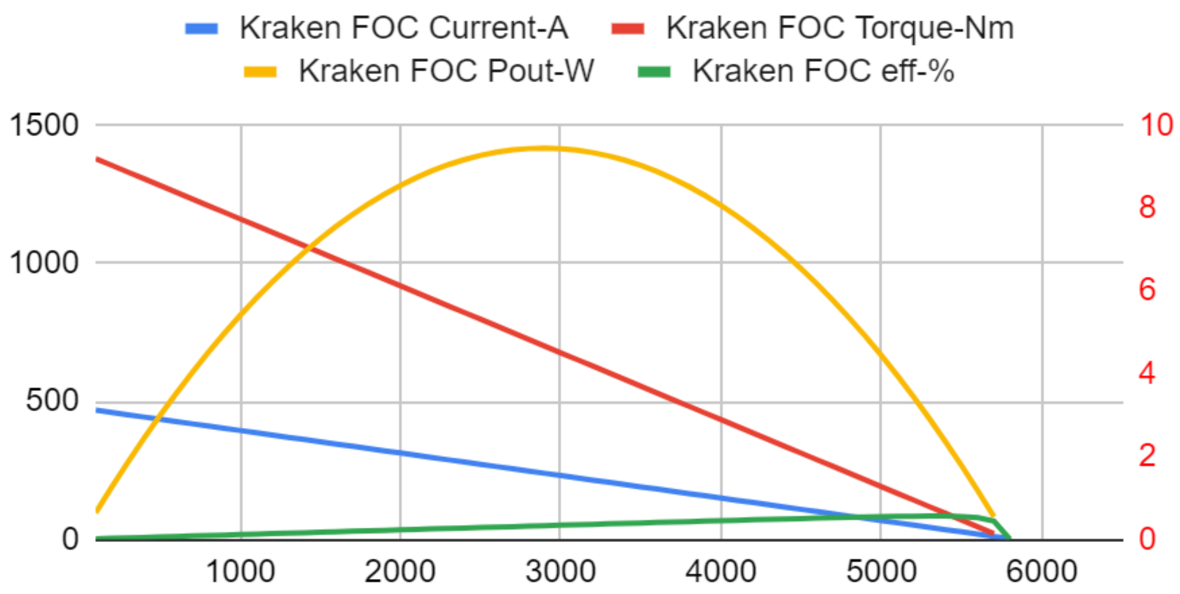





Falcon Current-A
Falcon Torque-Nm
Falcon Pout-W
Falcon eff-%
1000
750
500
250
0
6
4
2
0
1000
2000
3000
4000
5000
6000


Falcon FOC Current-A
Falcon FOC Torque-Nm
Falcon FOC Pout-W
Falcon FOC eff-%
1250
1000
750
500
250
0
8
6
4
2
0
1000
2000
3000
4000
5000
6000

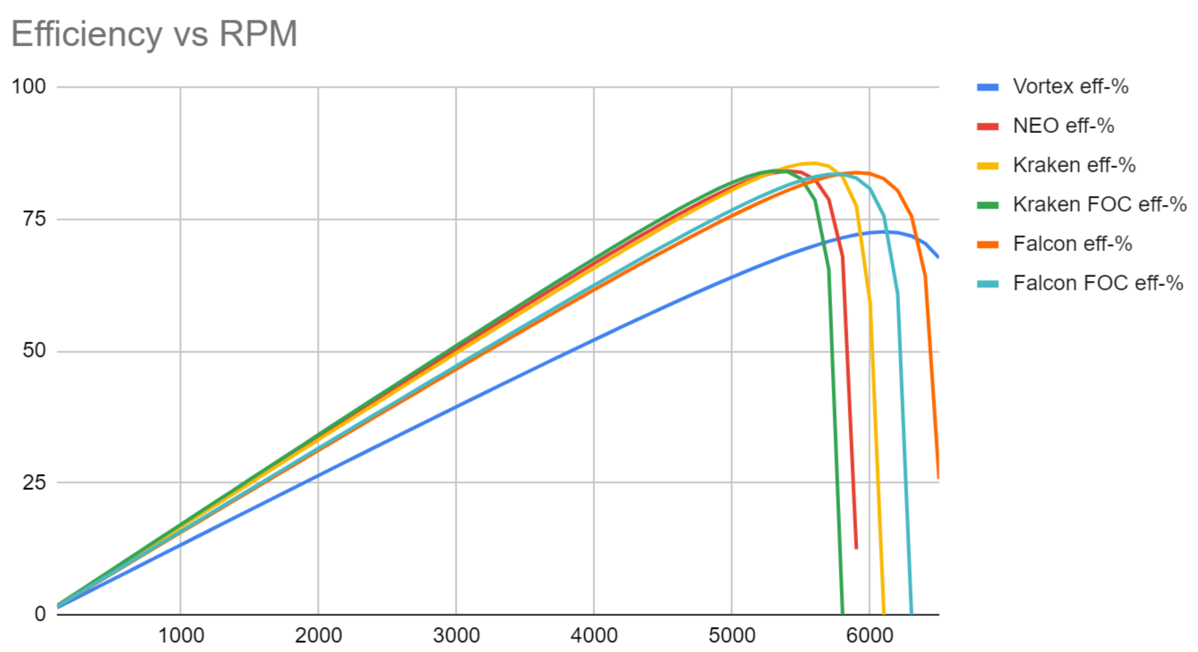

Kraken Current-A
Kraken Torque-Nm
Kraken Pout-W
Kraken eff-%
1250
1000
750
500
250
0
8
6
4
2
0
1000
2000
3000
4000
5000
6000

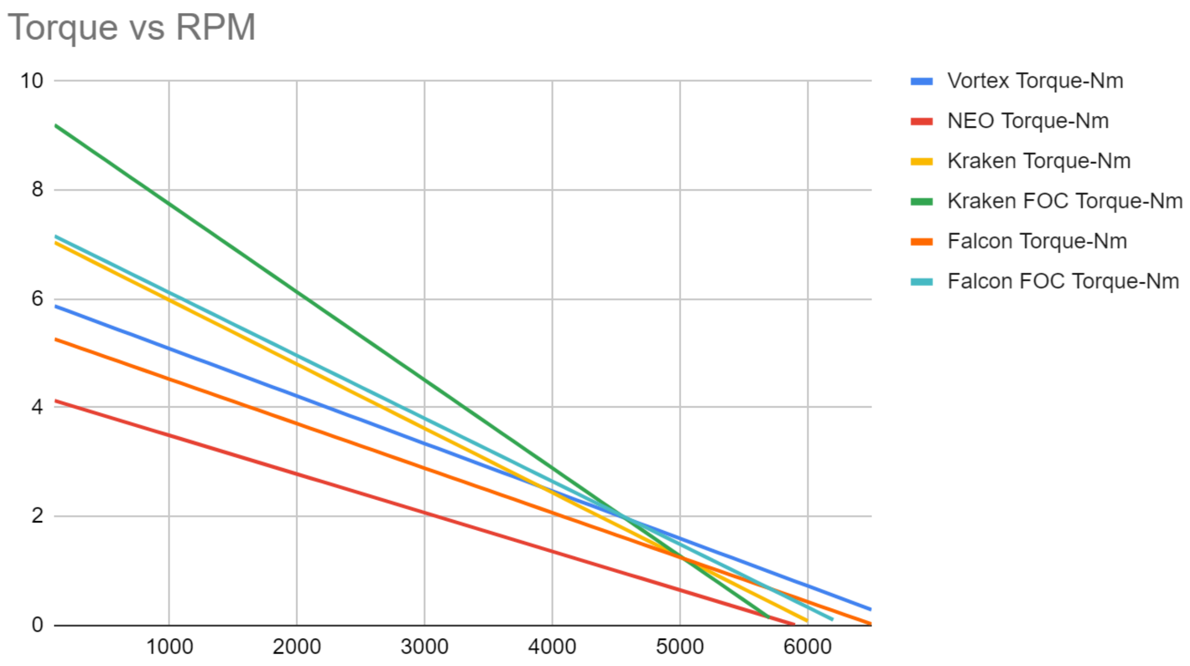

Kraken FOC Current-A
Kraken FOC Torque-Nm
Kraken FOC Pout-W
Kraken FOC eff-%
1500
1000
500
0
10
8
6
4
2
0
1000
2000
3000
4000
5000
6000

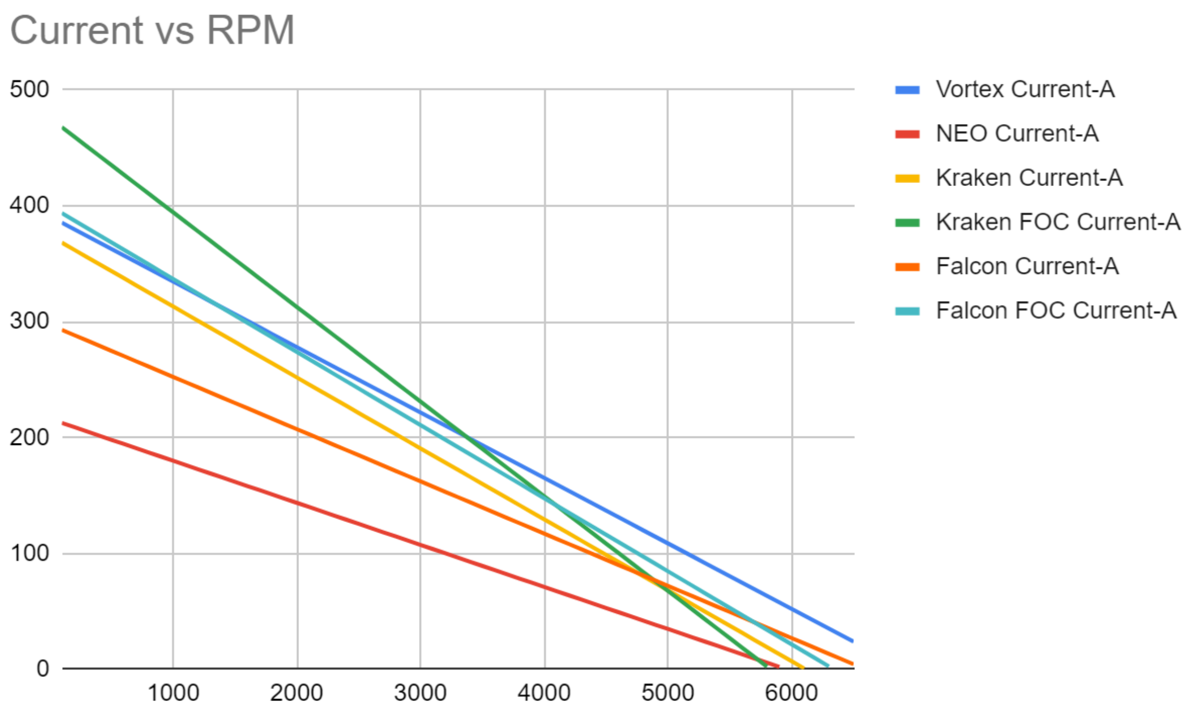
Motor Table

Parameter	NEO	Vortex	Falcon	Falcon FOC	Kraken	Kraken FOC	Units
Stall Current	216.27	391.09	297.45	400.06	374.38	476.10	A
Stall Torque	4.20	5.96	5.34	7.27	7.16	9.36	Nm
Peak Efficiency	84.14	72.61	83.85	83.51	85.62	84.18	%
Peak Power	649.45	1064.59	912.60	1196.24	1136.37	1417.72	W
Power @ 40 Amps	383.69	351.75	401.00	400.84	408.43	405.80	W
kT	19.57	15.46	18.17	18.33	19.26	19.81	mNm/A

Motor Comparisons




Torque vs RPM
10
8
6
4
2
0
1000
2000
3000
4000
5000
6000
Vortex Torque-Nm
NEO Torque-Nm
Kraken Torque-Nm
Kraken FOC Torque-Nm
Falcon Torque-Nm
Falcon FOC Torque-Nm


Current vs RPM
500
400
300
200
100
0
1000
2000
3000
4000
5000
6000
Vortex Current-A
NEO Current-A
Kraken Current-A
Kraken FOC Current-A
Falcon Current-A
Falcon FOC Current-A

Document Version

Version	Date	Information
1.0	1/15/2024	Initial Document Release