YEADON ENERGY SYSTEMS, INC.®

YES

ELECTROMAGNETIC SYSTEMS AND DEVICES

# REVISED REPORT:

# Electromagnetic Finite Element Analysis Dynamic Performance Analysis. 12 Motor Segment Configuration

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## Objective

Analyze geometry presented in YES report dated 9-27-2024. Evaluate 12 motor segments fixed to a common shaft. The 12 motor segments are simultaneously energized to produce torque. Coil groups will be connected in parallel for a total of 6 separately excited circuits per machine.

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## Procedure

- 2D Electromagnetic Finite Element Plots
- Dynamic performance calculations at following speeds (RPM)
    - 10,15,18,21,24,27,30,35,40,45,50

## Discussion

Figure 1 shows the individual coil electromagnet design model. The stack length is modeled at 4". The radial air gap is modeled at 0.075". This is a reasonable air gap at a 4.297 foot radius.

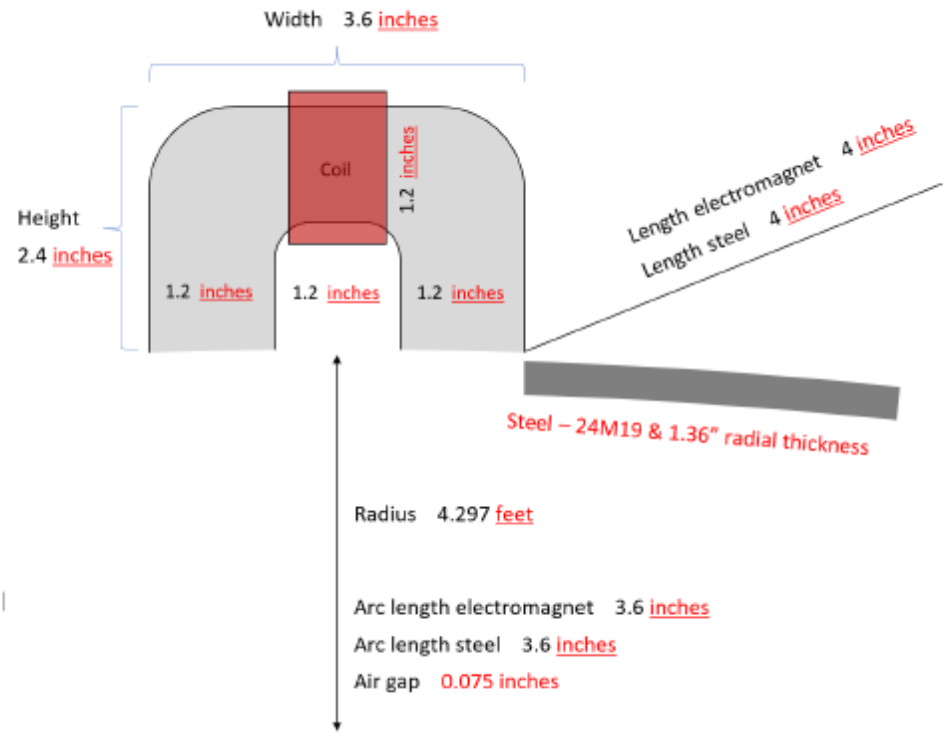


Figure 1- Device Dimensions

The active electromagnetic materials used for the analysis are as follows:

- Electrical Steel Laminations – 24M19
- Coil – Heavy Build Copper magnet wire

Figure 2 shows the finite element flux plot of the device at 10000 A-T per coil. The peak flux density is 1.625T. We are approaching the upper limit of the steel magnetic induction capability of ~1.7T.

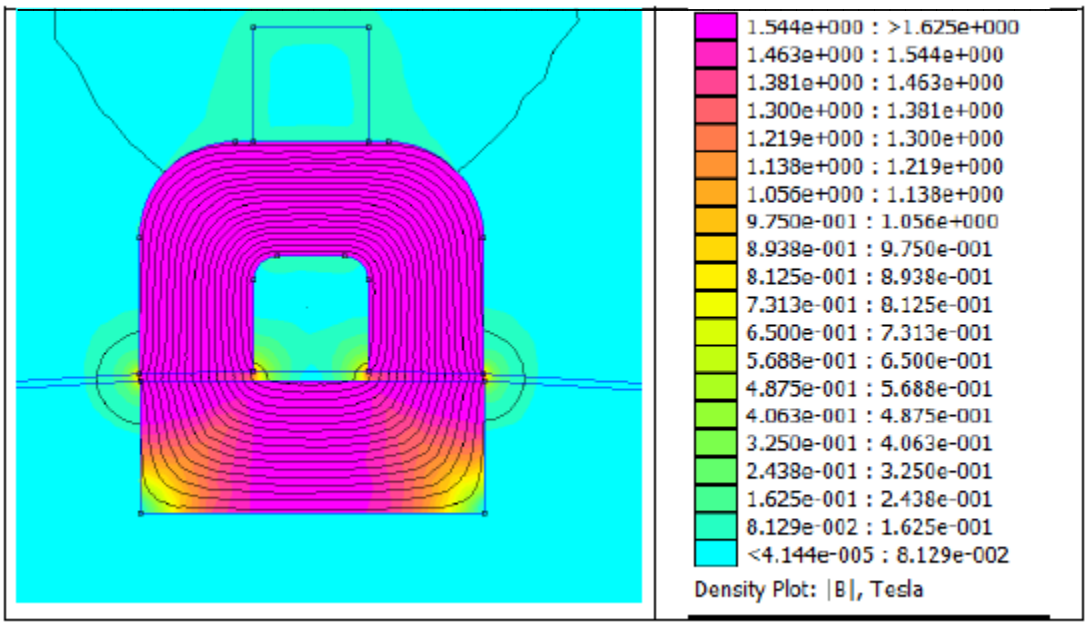


**Figure 2- Flux Plot 10000 A-T**

Figure 3 illustrates one Motor Segment. Each motor segment comprises a rotor with 30 electrical steel lamination cores and a stator with 24 stationary electromagnets. 12 top electromagnets and 12 bottom electromagnets.

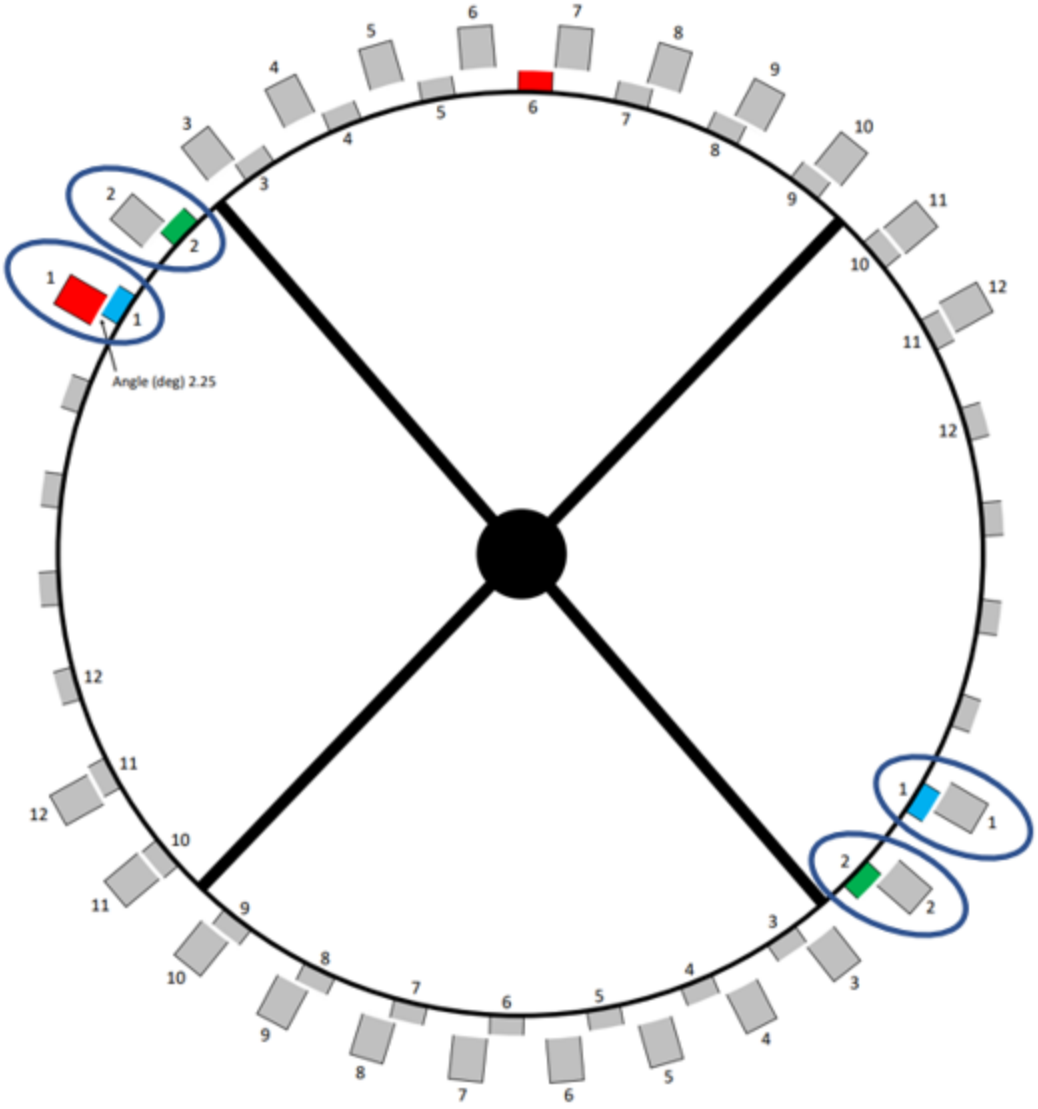


Figure 3 – 1 Motor Segment

The stator/rotor pairs within the 12 Motor Segments will be energized 1,2,3,etc. as follows.

- 12 stationary electromagnets are positioned at the top of the rotor and 12 stationary electromagnets are positioned at the bottom of the rotor.
- There are 12 sets of 2 stationary electromagnets.
- Each set is comprised of 1 stationary electromagnet from the ‘top’ and 1 stationary electromagnet from the ‘bottom.’ The center point of the respective electromagnet at the bottom is positioned 180-degrees opposite the center point of its respective ‘top’ electromagnet.
- Each Set is identified by a Set number (numbered 1 thru 12).

- The distance between the center point of each steel plate is 12-degrees. The steel plate respective to each Set is identified with same Set number.
- Each Set is energized in order by Set number (1 thru 12).
- One Set of two stationary electromagnets per motor segment causes two steel plates to be pulled counterclockwise at the same time, thereby doubling the torque per respective Angle (deg).
- The rotor turns 1-degree counterclockwise per operation of each set of two electromagnets.
- Set #1 is energized when the respective steel plate is positioned at Angle (deg) 2.25. Set #1 is de-energized when its respective steel plate is positioned at Angle (deg) 3.25.
- After said 1-degree rotation, the steel plate respective to Set #2 is positioned at Angle (deg) 2.25.
- Set #2 is energized when the respective steel plate is positioned at Angle (deg) 2.25. Set #2 is de-energized when its respective steel plate is positioned at Angle (deg) 3.25.
- After said 1-degree rotation, the steel plate respective to Set #3 is positioned at Angle (deg) 2.25.
- Set #3 is energized when the respective steel plate is positioned at Angle (deg) 2.25. Set #3 is de-energized when its respective steel plate is positioned at Angle (deg) 3.25.
- The 1-degree counterclockwise rotation repeats 12 times (1-degree per Set), causing the rotor to rotate 12-degrees counterclockwise.
- At the conclusion of 12-degrees of counterclockwise rotation (operation of all 12 Sets), the steel plates highlighted **green** will have rotated 12 degrees counterclockwise to the positions highlighted **blue** (Angle (deg) 2.25), enabling the process of rotation to repeat via the 12 Sets (again) energized in numerical order.
- Regardless of the position of the rotor, one set of electromagnets is always energized.

The subsequent analysis discussion is based off the 12 Motor Segment approach with 24 electromagnets energized. There are 6 pairs of identical motor segments, each pair powered by a separate circuit. Each circuit provides power in numerical order to each of the 12 respective pairs of electromagnets as shown in figure 4 machine side view.

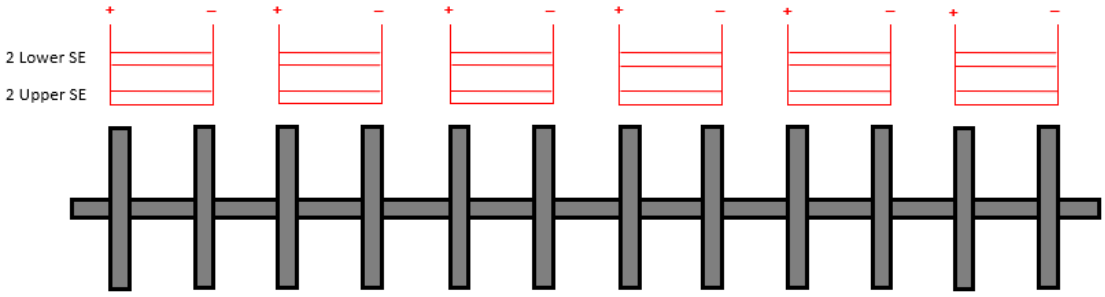


Figure 4 – Machine Side View. SE = Stationary Electromagnets.

Figure 5 shows torque versus position for 2 consecutive excitation periods. The total line current is 95.2A per circuit or 23.8A/ motor segment. The minimum torque produced is 13797. ft-lbs.

This analysis shows a line current of 107.5A per circuit is required to produce a minimum torque of 17,592 ft-lbs.

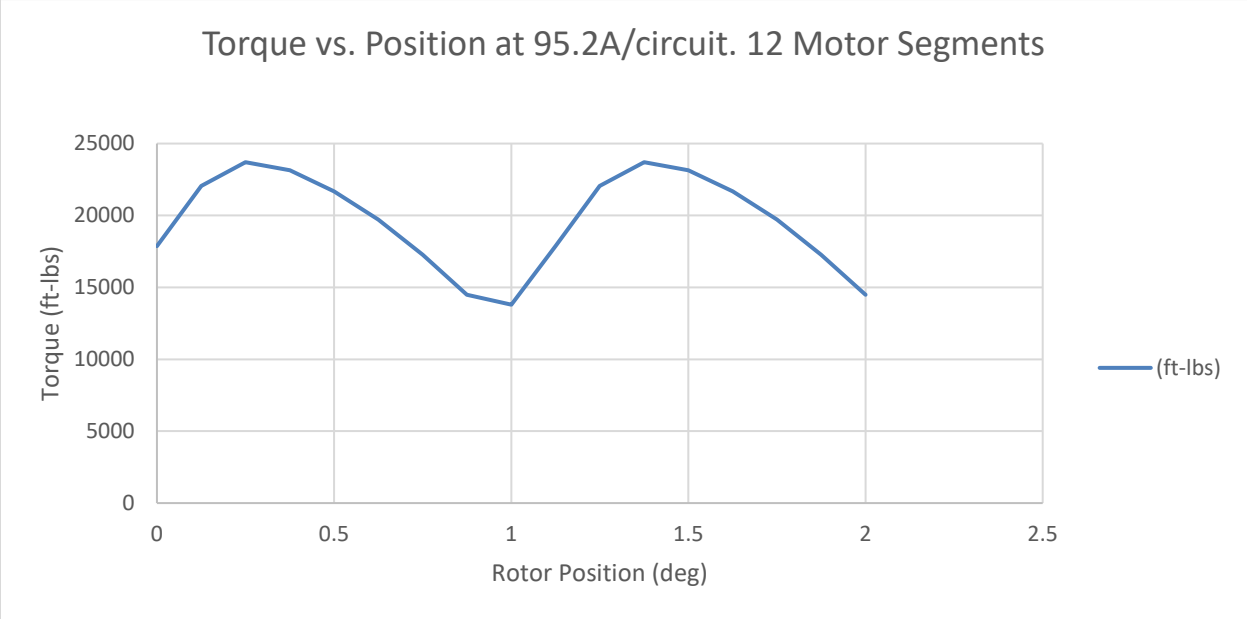


Figure 5 - Torque vs. Position @ Constant Current

Table1 shows the raw data from the torque analysis shown in figure 5.

| Torque | (ft-lbs) |
|---|---|
| 0 | 17863.8 |
| 0.125 | 22053.6 |
| 0.25 | 23704.2 |
| 0.375 | 23136 |
| 0.5 | 37870.8 |
| 0.625 | 19713.6 |
| 0.75 | 17277.6 |
| 0.875 | 14494.8 |
| 1 | 13797 |
| 1.125 | 17863.8 |
| 1.25 | 22053.6 |
| 1.375 | 23704.2 |
| 1.5 | 23136 |
| 1.625 | 21670.8 |
| 1.75 | 19713.6 |
| 1.875 | 17277.6 |
| 2 | 14494.8 |

**Table 1 – Raw Torque Data 95.2A per circuit**

Coil specifications for the machine are as follows:

- 420T of 15.5AWG Heavy Build

Figure 6 shows the excitation flux plot for 1 Motor Segment energized.

Figure 7 shows the dynamic performance plot of the machine at a constant torque of 17,592 ft-lbs. Performance raw data is shown in table 2.

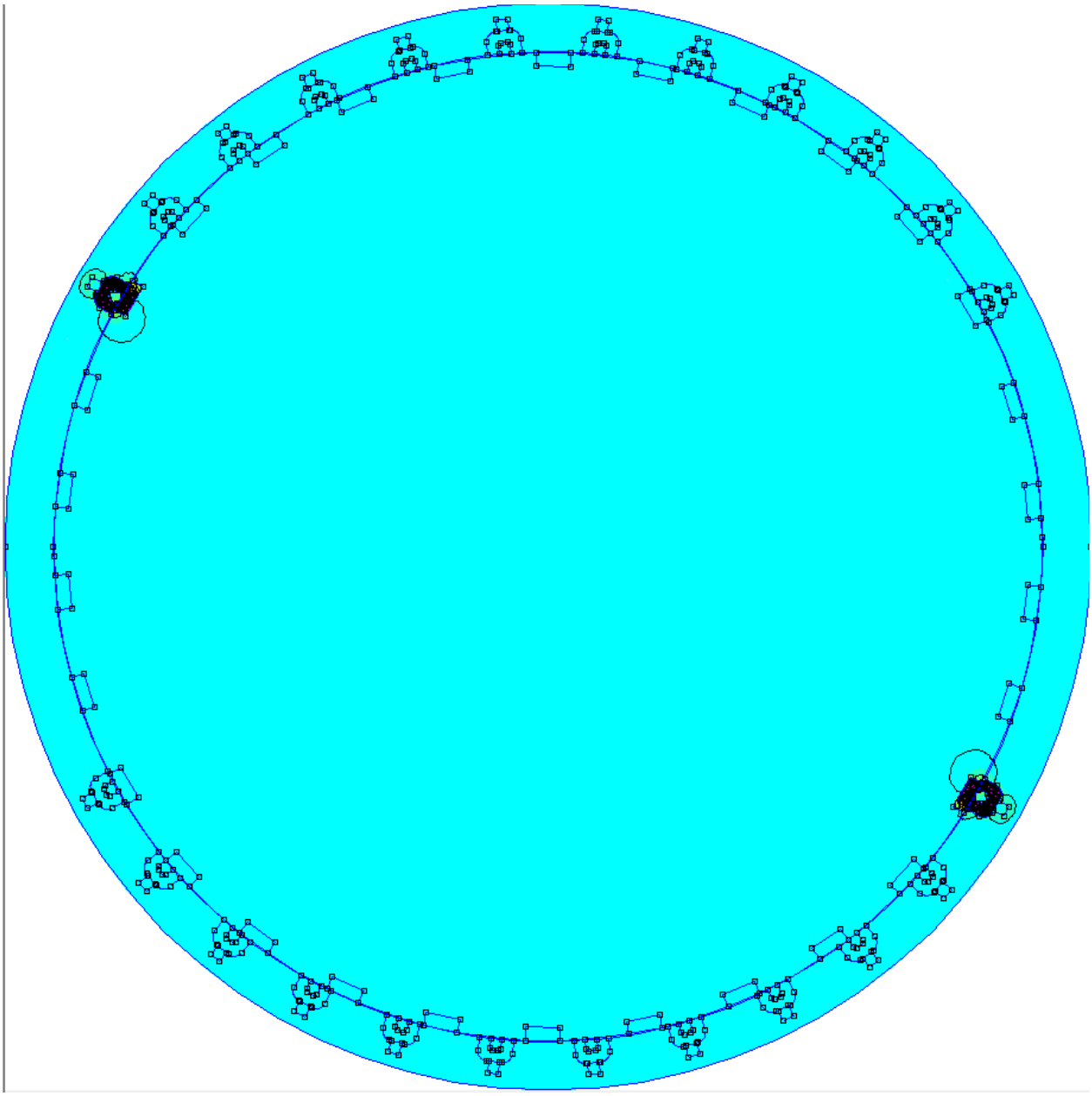

Figure 6 - Total Module Flux Plot

**Figure 7 – Dynamic Performance Curves**

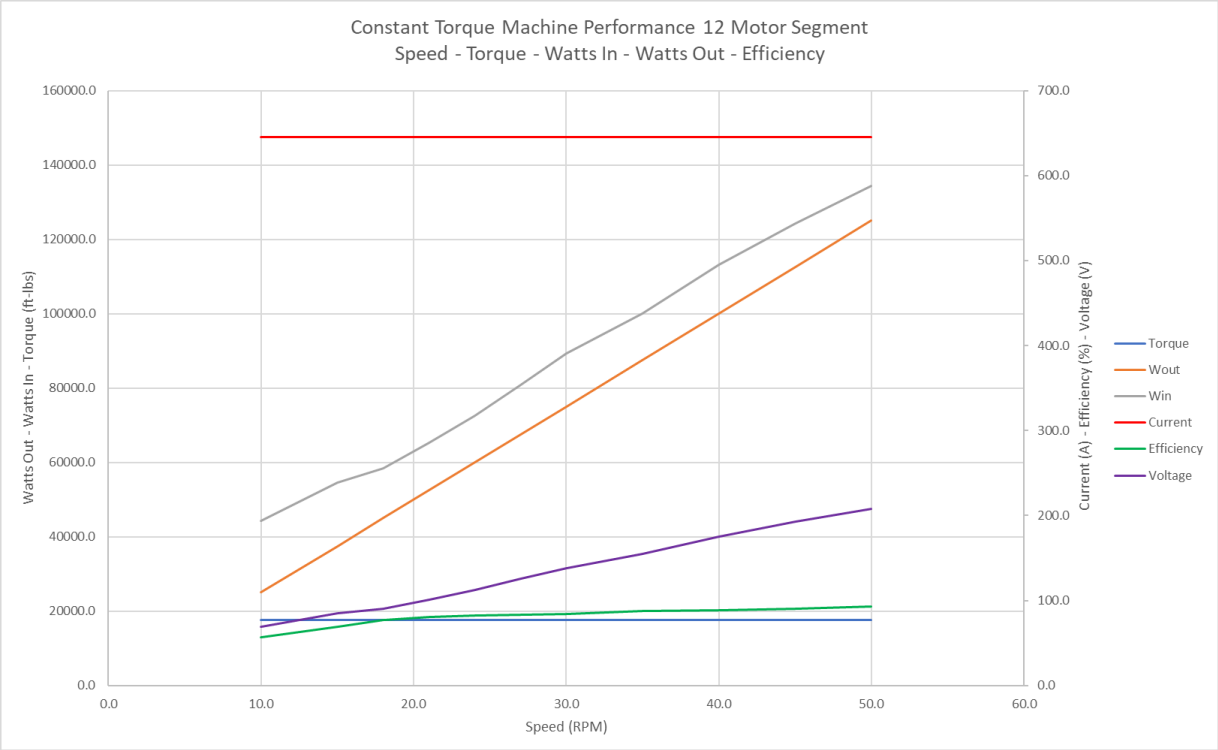


**Table 2 – Dynamic Performance Raw Data**

| Torque (ft-lbs)) | Speed (RPM) | Wout | Current (A) | Voltage | Win | Eff (%) |
|---|---|---|---|---|---|---|
| 17592.0 | 50.0 | 124982.4 | 645.0 | 208.2 | 134289.0 | 93.1 |
| 17592.0 | 45.0 | 112484.1 | 645.0 | 192.5 | 124162.5 | 90.6 |
| 17592.0 | 40.0 | 99985.9 | 645.0 | 175.4 | 113133.0 | 88.4 |
| 17592.0 | 35.0 | 87487.7 | 645.0 | 155.2 | 100104.0 | 87.4 |
| 17592.0 | 30.0 | 74989.4 | 645.0 | 138.4 | 89268.0 | 84.0 |
| 17592.0 | 27.0 | 67490.5 | 645.0 | 125.4 | 80883.0 | 83.4 |
| 17592.0 | 24.0 | 59991.5 | 645.0 | 112.4 | 72498.0 | 82.7 |
| 17592.0 | 21.0 | 52492.6 | 645.0 | 101.2 | 65274.0 | 80.4 |
| 17592.0 | 18.0 | 44993.7 | 645.0 | 90.7 | 58501.5 | 76.9 |
| 17592.0 | 15.0 | 37494.7 | 645.0 | 84.6 | 54567.0 | 68.7 |
| 17592.0 | 10.0 | 24996.5 | 645.0 | 68.7 | 44311.5 | 56.4 |

## Conclusions and Recommendations

Dynamic performance of the 12 motor segment device has been performed at a speed range of 10 to 50 RPM.

We conclude the following:

- The device is capable of a constant dynamic torque of 17,592 ft-lb, with each pair of identical motor segments powered by a separate circuit at a total line current of 107.5A from 10 to 50 RPM. Total machine current from the 6 circuits is 645 A.
- The device requires 208.2V to achieve this output at 50 RPM.

We recommend the following:

- Additional design effort is required to determine:
    - Develop commutation methods to ensure modules are synchronized
    - Thermal response