YEADON ENERGY SYSTEMS, INC.

ELECTROMAGNETIC SYSTEMS AND DEVICES

REVISED REPORT:

Electromagnetic Finite Element Analysis
Dynamic Performance Analysis. Dual Rotor/Stator Design

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Objective

Analyze dual rotor module design per design documentation dated 8-2-2022. Word document file "YES7-2segments.docx" and "YES8.docx" 36V Dynamic Performance Data. Torque, Speed, Wout, Current, Win , Eff (%). Coil commutation will be analyzed per the design concept shown and described in the"YES7-2segments.docx" and ""YES8.docx" document.

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Procedure

- 2D Electromagnetic Finite Element Plots
- Dynamic performance calculations to meet 2932 ft-lbs at following speeds (RPM)
  - 10,15,18,21,24,27,30,35,40,45,50

Discussion

Figure 1 shows the design modeled. 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.

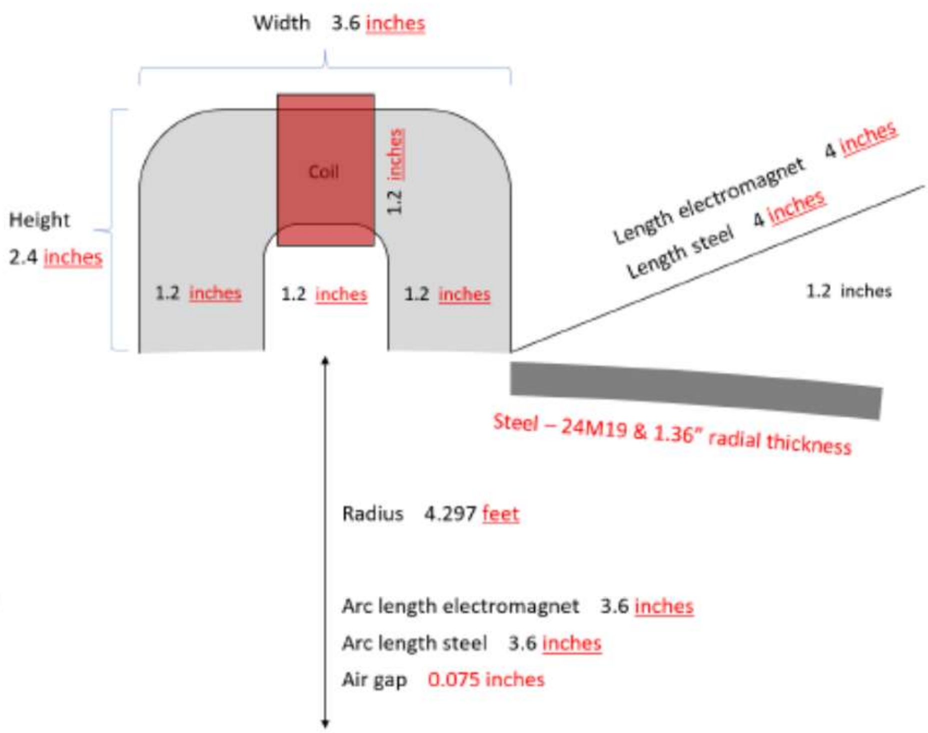

Figure 1- Device Dimensions

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.

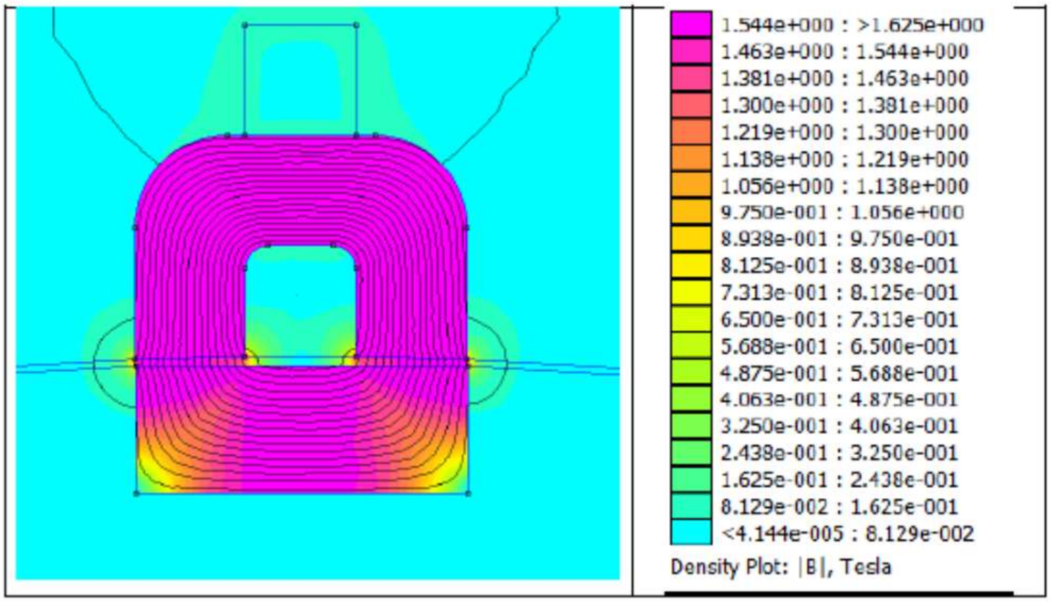

Figure 2- Flux Plot 10000 A-T

Figure 3 one stator and one rotor module assembly for the device.

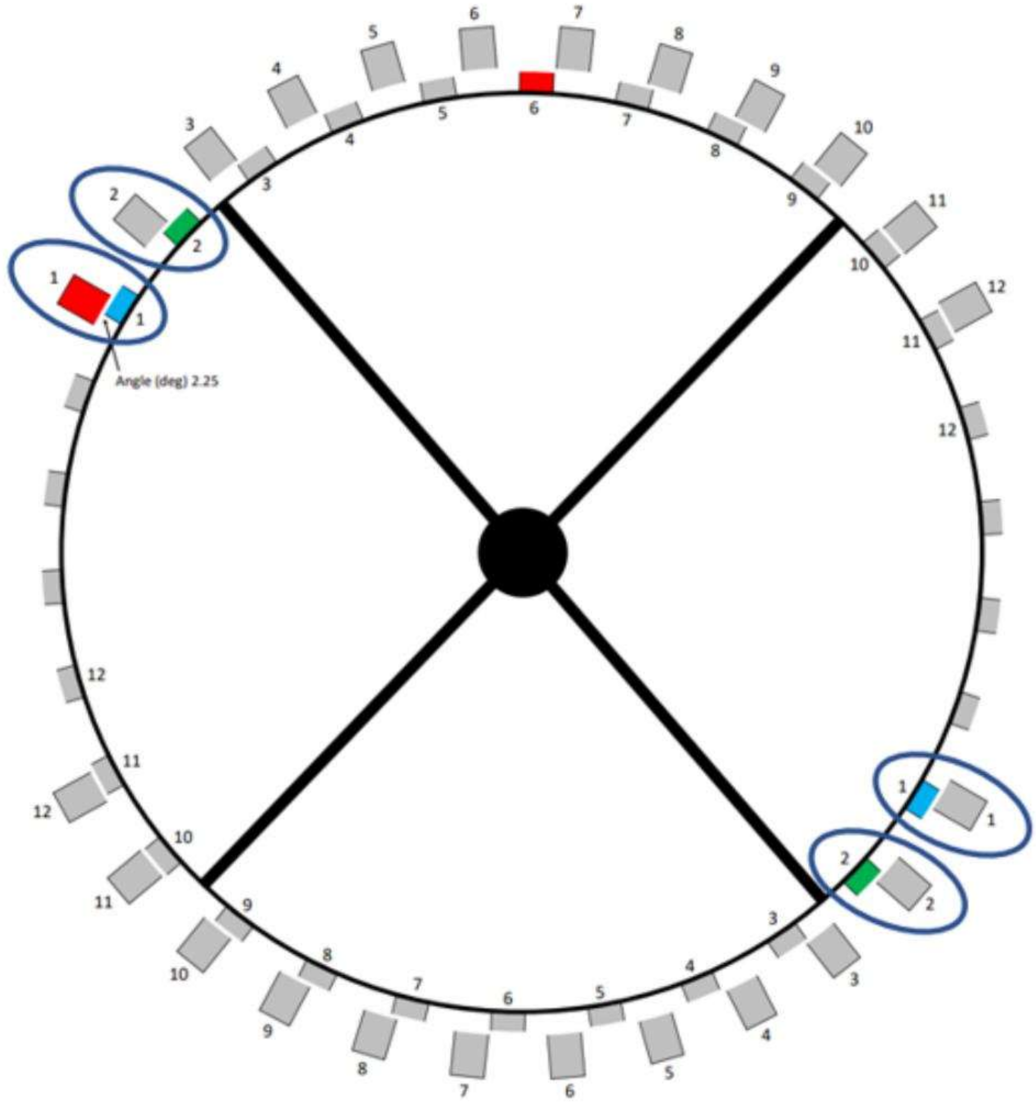

Figure 3 – 1 Stator and Rotor Module

The stator/rotor pairs 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.

Figure 4 shows 2 rotor/stator modules. The rotor modules are fixed to a common shaft. This will allow for a potential 4x torque production compared to a single pair of electromagnets.

The subsequent analysis discussion is based off the dual rotor/stator module approach.

Figure 4 - Dual Module Side View

Figure 5 shows torque versus position for 2 consecutive excitation periods. The total line current is 95.2A or 23.8A/ module. The minimum torque produced is 2299.5 ft-lbs.

This analysis shows a line current of 107.5A is required to produce a minimum torque of 2932 ft-lbs per the dynamic requirements.

Figure 5 - Torque vs. Position @ Constant Current

Table1 shows the raw data from the torque analysis shown in figure 3.

Rotor Position	Torque (ft-lbs)
0	2977.3
0.125	3675.6
0.25	3950.7
0.375	3856.0
0.5	3611.8
0.625	3285.6
0.75	2879.6
0.875	2415.8
1	2299.5
1.125	2977.3
1.25	3675.6
1.375	3950.7
1.5	3856.0
1.625	3611.8
1.75	3285.6
1.875	2879.6
2	2415.8

Table 1 – Raw Torque Data 95.2A

Coil specifications for the machine is as follows:

- 420T of 15.5 AWG Heavy Build

Figure 6 shows the complete excitation flux plot for one rotor/stator module

Figure 7 shows the dynamic performance plot of the machine at a constant torque of 2932 ft-lbs. Performance raw data is shown in table 2.

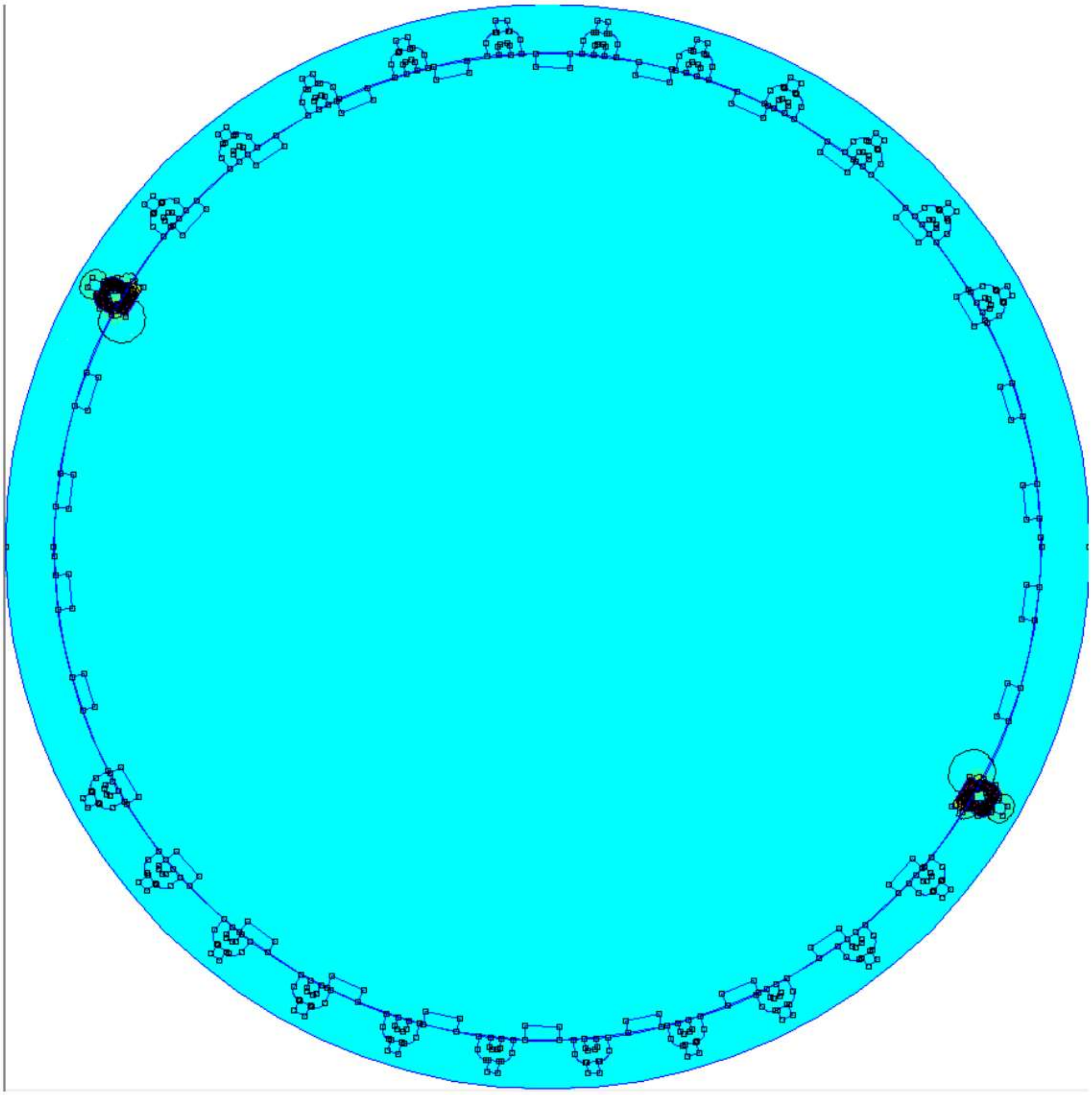

Figure 6 - Total Module Flux Plot

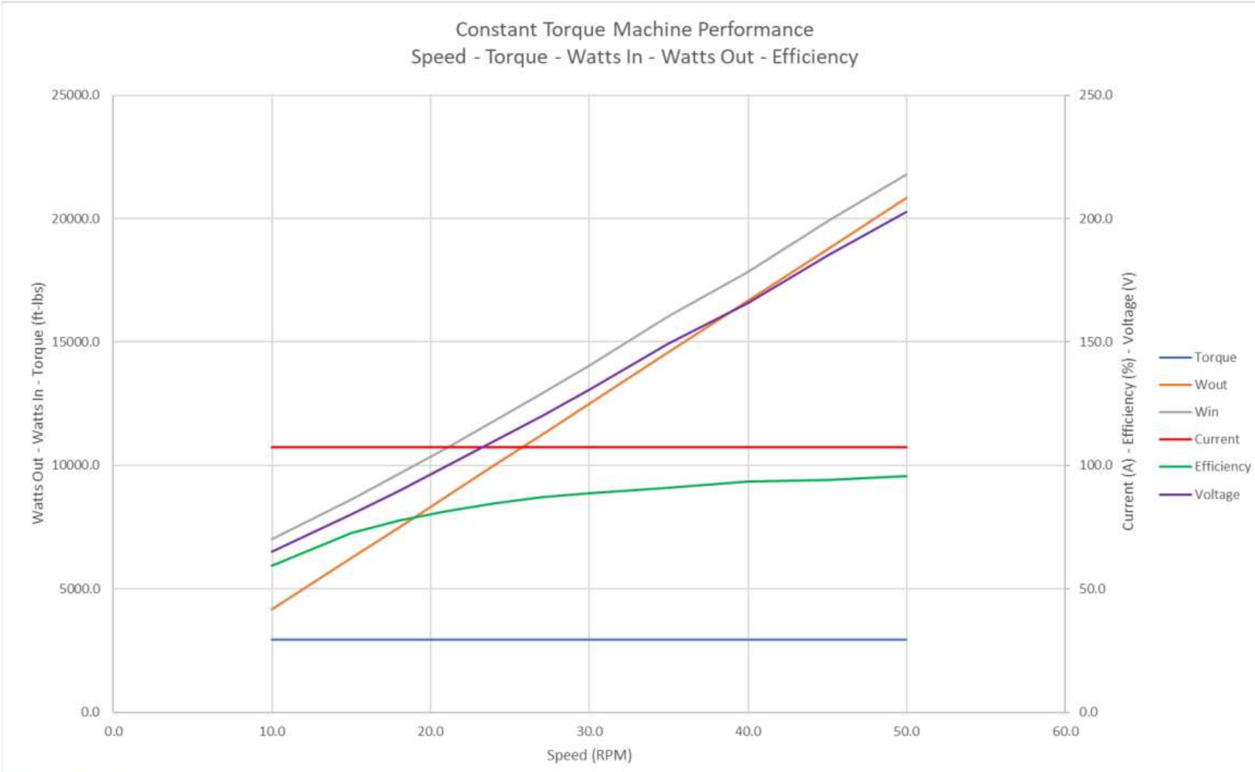

Figure 7 – Dynamic Performance Curves

Table 2 – Dynamic Performance Raw Data

Torque (ft-lbs))	Speed (RPM)	Wout	Current (A)	Voltage	Win	Eff (%)
2932.0	50.0	20830.4	107.5	202.6	21779.5	95.6
2932.0	45.0	18747.4	107.5	185.0	19887.5	94.3
2932.0	40.0	16664.3	107.5	165.8	17823.5	93.5
2932.0	35.0	14581.3	107.5	149.2	16039.0	90.9
2932.0	30.0	12498.2	107.5	130.8	14061.0	88.9
2932.0	27.0	11248.4	107.5	120.1	12910.8	87.1
2932.0	24.0	9998.6	107.5	109.8	11803.5	84.7
2932.0	21.0	8748.8	107.5	99.7	10717.8	81.6
2932.0	18.0	7498.9	107.5	89.8	9653.5	77.7
2932.0	15.0	6249.1	107.5	80.1	8610.8	72.6
2932.0	10.0	4166.1	107.5	65.2	7009.0	59.4

Conclusions and Recommendations

Dynamic performance of the dual segment device has been performed in the speed range of 10 to 50 RPM.

We conclude the following:

- The device is capable of a constant dynamic torque of 2932 ft-lb at a total line current of 107.5A from 10 to 50 RPM.
- The device requires 202.6 V to achieve this output at 50 RPM.

We recommend the following:

- Additional design effort is required to determine:
    - Optimal commutation methods
    - Thermal response