Rmxprt

First model was created on rmxprt. Figure 1 shows the model.

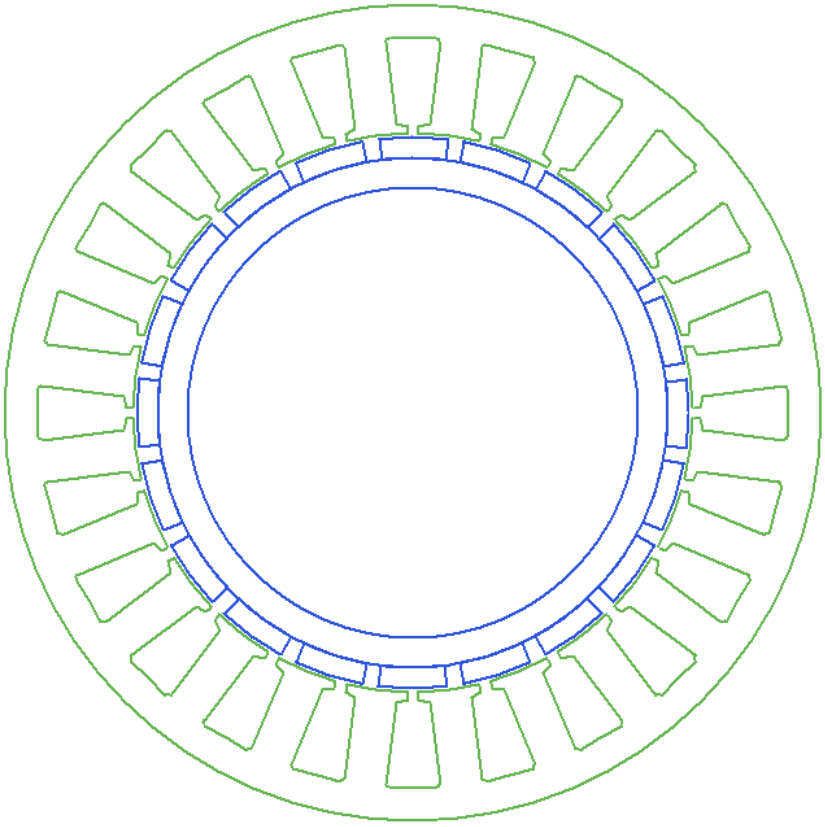

Figure 1

Fallowing figures show rmxpert results.

Data: Material Consumption

	Name	Value	Units	Description
1	Armature Wire Density	8900	kg_per_m3	Mass Density
2	Permanent Magnet Density	7400	kg_per_m3	Mass Density
3	Armature Core Steel Density	7872	kg_per_m3	Mass Density
4	Rotor Core Steel Density	7872	kg_per_m3	Mass Density
5	Armature Copper Weight	5.0657	kg	
6	Permanent Magnet Weight	3.24792	kg	
7	Armature Core Steel Weight	20.6809	kg	
8	Rotor Core Steel Weight	4.98392	kg	
9	Total Net Weight	33.9785	kg	
10	Armature Core Steel Consumption	78.0301	kg	
11	Rotor Core Steel Consumption	30.9737	kg	

Figure 2

	Name	Value	Units	Description
1	Stator-Teeth Flux Density	1.6459	tesla	
2	Stator-Yoke Flux Density	1.03734	tesla	
3	Rotor-Yoke Flux Density	1.23753	tesla	
4	Air-Gap Flux Density	0.958499	tesla	
5	Magnet Flux Density	1.03466	tesla	
6	Stator-Teeth Ampere Turns	149.485	A.T	
7	Stator-Yoke Ampere Turns	1.5823	A.T	
8	Rotor-Yoke Ampere Turns	10.4134	A.T	
9	Air-Gap Ampere Turns	1244.79	A.T	
10	Magnet Ampere Turns	-1406.16	A.T	
11	Start Armature Reactive AT	3531.11	A.T	The worse armature reactive amper turns
12	Leakage-Flux Factor	1		
13	Stator Yoke Correction Factor	0.667366		Correction factor for stator yoke magnetic circuit length
14	Rotor Yoke Correction Factor	0.59941		Correction factor for rotor yoke magnetic circuit length
15	Cogging Torque	0.853601	NewtonMeter	

Figure 3

	Name	Value	Units	Description
1	Minimum Air Gap	1.5	mm	
2	Polar Arc Radius	91.5	mm	
3	Mechanical Pole Embrace	0.81		
4	Electrical Pole Embrace	0.780909		

Figure 4

	Name	Value	Units	Description
1	Slot Type	3		
2	hs0	2	mm	
3	hs1	1	mm	
4	hs2	27	mm	
5	bs0	4	mm	
6	bs1	11.1508	mm	
7	bs2	18.26	mm	
8	rs	1	mm	
9	Top Tooth Width	14	mm	
10	Bottom Tooth Width	14	mm	

Figure 5

	Name	Value	Units	Description
1	Number of Conductors per Slot	70		
2	Number of Strands	1		
3	Wire Diameter	1.628	mm	
4	Wire Wrap	0	mm	
5	Average Coil Pitch	1	slot	
6	Stator Slot Fill Factor	44.7185	%	
7	Coil Half-Turn Length	162.758	mm	

Figure 6

	Name	Value	Units	Description
1	Stator Winding Factor	0.933013		
2	D-Axis Reactive Inductance Lad	694975	nH	
3	Q-Axis Reactive Inductance Laq	694975	nH	
4	D-Axis Inductance L1+Lad	3600480	nH	
5	Q-Axis Inductance L1+Laq	3600480	nH	
6	Armature Leakage Inductance L1	2905500	nH	
7	Zero-Sequence Inductance L0	2379860	nH	
8	Armature Phase Resistance R1	0.237537	ohm	
9	D-Axis Time Constant	2925760	ns	
10	Q-Axis Time Constant	2925760	ns	

Figure 7

GENERAL DATA

Rated Output Power (kW):	8
Rated Voltage (V):	304
Number of Poles:	20
Frequency (Hz):	100
Frictional Loss (W):	0
Windage Loss (W):	0
Rotor Position:	Inner
Type of Circuit:	Y3
Type of Source:	Sine
Domain:	Time
Operating Temperature (C):	75

STATOR DATA

Number of Stator Slots:	24
Outer Diameter of Stator (mm):	270
Inner Diameter of Stator (mm):	186
Type of Stator Slot:	3
Stator Slot	
hs0 (mm):	2
hs1 (mm):	1
hs2 (mm):	27
bs0 (mm):	4
bs1 (mm):	11.1508
bs2 (mm):	18.26
rs (mm):	1
Top Tooth Width (mm):	14
Bottom Tooth Width (mm):	14
Skew Width (Number of Slots):	0
Length of Stator Core (mm):	140
Stacking Factor of Stator Core:	0.95
Type of Steel:	m250-35a
Designed Wedge Thickness (mm):	1.00004
Slot Insulation Thickness (mm):	0
Layer Insulation Thickness (mm):	0
End Length Adjustment (mm):	0
Number of Parallel Branches:	2
Number of Conductors per Slot:	70
Type of Coils:	21
Average Coil Pitch:	1
Number of Wires per Conductor:	1
Wire Diameter (mm):	1.628
Wire Wrap Thickness (mm):	0
Slot Area (mm^2):	430.453
Net Slot Area (mm^2):	414.877
Limited Slot Fill Factor (%):	75
Stator Slot Fill Factor (%):	44.7185
Coil Half-Turn Length (mm):	162.758
Wire Resistivity (ohm.mm^2/m):	0.0217

Figure 8

ROTOR DATA

Minimum Air Gap (mm):	1.5
Inner Diameter (mm):	150
Length of Rotor (mm):	140
Stacking Factor of Iron Core:	0.95
Type of Steel:	steel_1010
Polar Arc Radius (mm):	91.5
Mechanical Pole Embrace:	0.81
Electrical Pole Embrace:	0.780909
Max. Thickness of Magnet (mm):	7
Width of Magnet (mm):	22.3933
Type of Magnet:	NdFe45
Type of Rotor:	1
Magnetic Shaft:	No

PERMANENT MAGNET DATA

Residual Flux Density (Tesla):	1.35
Coercive Force (kA/m):	860
Maximum Energy Density (kJ/m^3):	290.25
Relative Recoil Permeability:	1.24922
Demagnetized Flux Density (Tesla):	0
Recoil Residual Flux Density (Tesla):	1.35
Recoil Coercive Force (kA/m):	860

MATERIAL CONSUMPTION

Armature Wire Density (kg/m^3):	8900
Permanent Magnet Density (kg/m^3):	7400
Armature Core Steel Density (kg/m^3):	7872
Rotor Core Steel Density (kg/m^3):	7872
Armature Copper Weight (kg):	5.0657
Permanent Magnet Weight (kg):	3.24792
Armature Core Steel Weight (kg):	20.6809
Rotor Core Steel Weight (kg):	4.98392
Total Net Weight (kg):	33.9785
Armature Core Steel Consumption (kg):	78.0301
Rotor Core Steel Consumption (kg):	30.9737

STEADY STATE PARAMETERS

Stator Winding Factor:	0.933013
D-Axis Reactive Inductance Lad (H):	0.000694975
Q-Axis Reactive Inductance Laq (H):	0.000694975
D-Axis Inductance L1+Lad (H):	0.00360048
Q-Axis Inductance L1+Laq (H):	0.00360048
Armature Leakage Inductance L1 (H):	0.0029055
Zero-Sequence Inductance L0 (H):	0.00237986
Armature Phase Resistance R1 (H):	0.237537
Armature Phase Resistance at 20C (ohm):	0.195393

Figure 9

NO-LOAD MAGNETIC DATA

Stator-Teeth Flux Density (Tesla):	1.6459
Stator-Yoke Flux Density (Tesla):	1.03734
Rotor-Yoke Flux Density (Tesla):	1.23753
Air-Gap Flux Density (Tesla):	0.958499
Magnet Flux Density (Tesla):	1.03466
Stator-Teeth By-Pass Factor:	0.00466717
Stator-Yoke By-Pass Factor:	7.46116e-00
Rotor-Yoke By-Pass Factor:	7.54481e-00
Stator-Teeth Ampere Turns (A.T):	149.485
Stator-Yoke Ampere Turns (A.T):	1.5823
Rotor-Yoke Ampere Turns (A.T):	10.4134
Air-Gap Ampere Turns (A.T):	1244.79
Magnet Ampere Turns (A.T):	-1406.16
Leakage-Flux Factor:	1
Correction Factor for Magnetic Circuit Length of Stator Yoke:	0.667366
Correction Factor for Magnetic Circuit Length of Rotor Yoke:	0.59941
No-Load Line Current (A):	1.30106
No-Load Input Power (W):	137.505
Cogging Torque (N.m):	0.853601

FULL-LOAD DATA

Maximum Line Induced Voltage (V):	426.066
Root-Mean-Square Line Current (A):	15.5964
Root-Mean-Square Phase Current (A):	15.5964
Armature Thermal Load (A^2/mm^3):	83.9915
Specific Electric Loading (A/mm):	22.4202
Armature Current Density (A/mm^2):	3.74623
Frictional and Windage Loss (W):	0
Iron-Core Loss (W):	136.046
Armature Copper Loss (W):	173.34
Total Loss (W):	309.386
Output Power (W):	8001.82
Input Power (W):	8311.21
Efficiency (%):	96.2775
Synchronous Speed (rpm):	600
Rated Torque (N.m):	127.353
Torque Angle (degree):	11.6057
Maximum Output Power (W):	35133.9

Figure 10

TRANSIENT FEA INPUT DATA

For Armature Winding:	
Number of Turns:	280
Parallel Branches:	2
Terminal Resistance (ohm):	0.237537
End Leakage Inductance (H):	1.17576e-005
2D Equivalent Value:	
Equivalent Model Depth (mm):	140
Equivalent Stator Stacking Factor:	0.95
Equivalent Rotor Stacking Factor:	0.95
Equivalent Br (Tesla):	1.35
Equivalent Hc (kA/m):	860
Estimated Rotor Inertial Moment (kg m^2):	0.120234

Figure 11

2D Design

Figure… shows the modified cross section of the motor. Small slots are placed at the end of slots in order to secure the windings. Magnet shape is changed in order to decrease cogging torque and torque ripple.

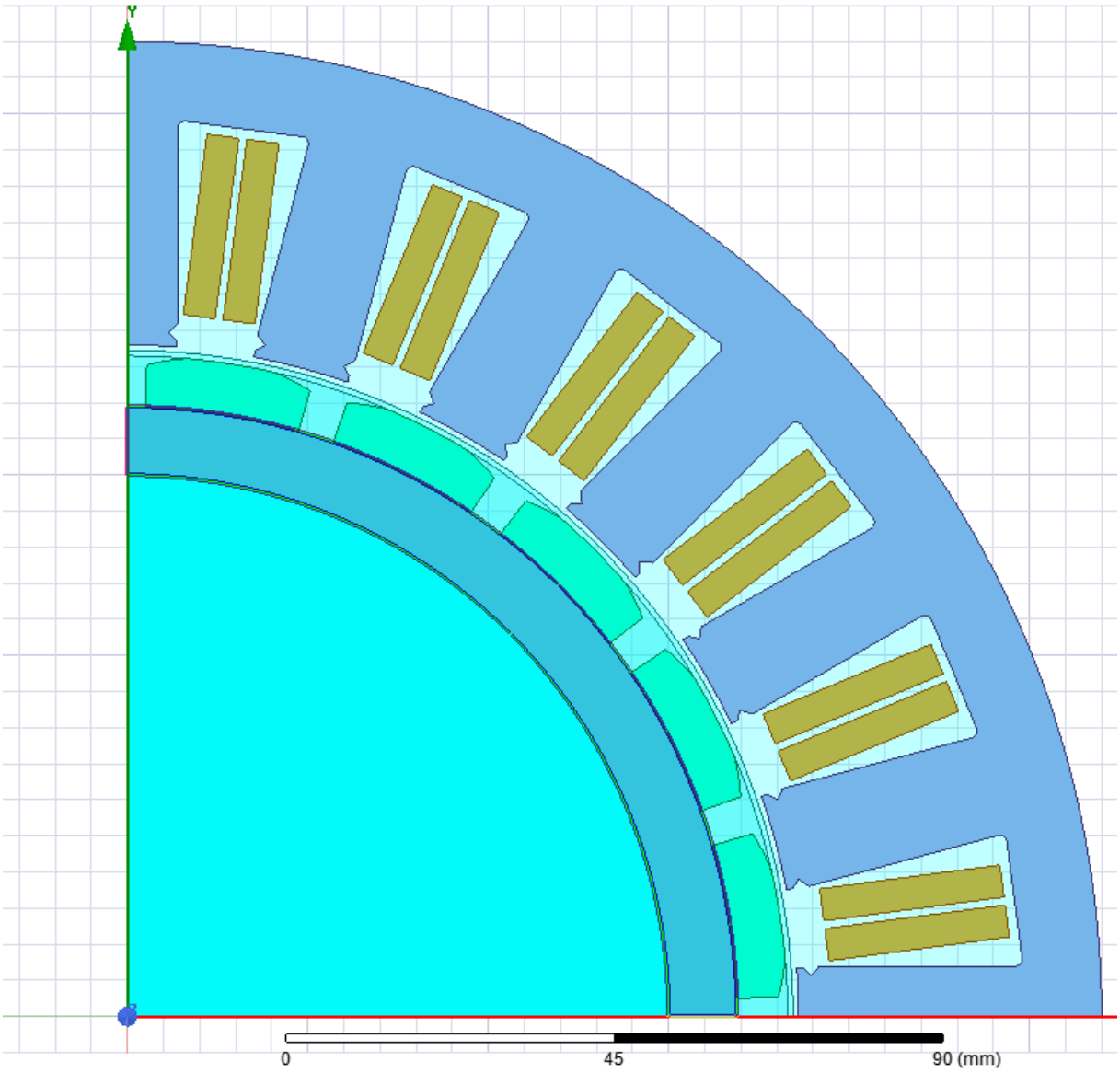

Figure 12

Figure… shows the input and output powers of the motor. Rated output power is 8.5 kW.

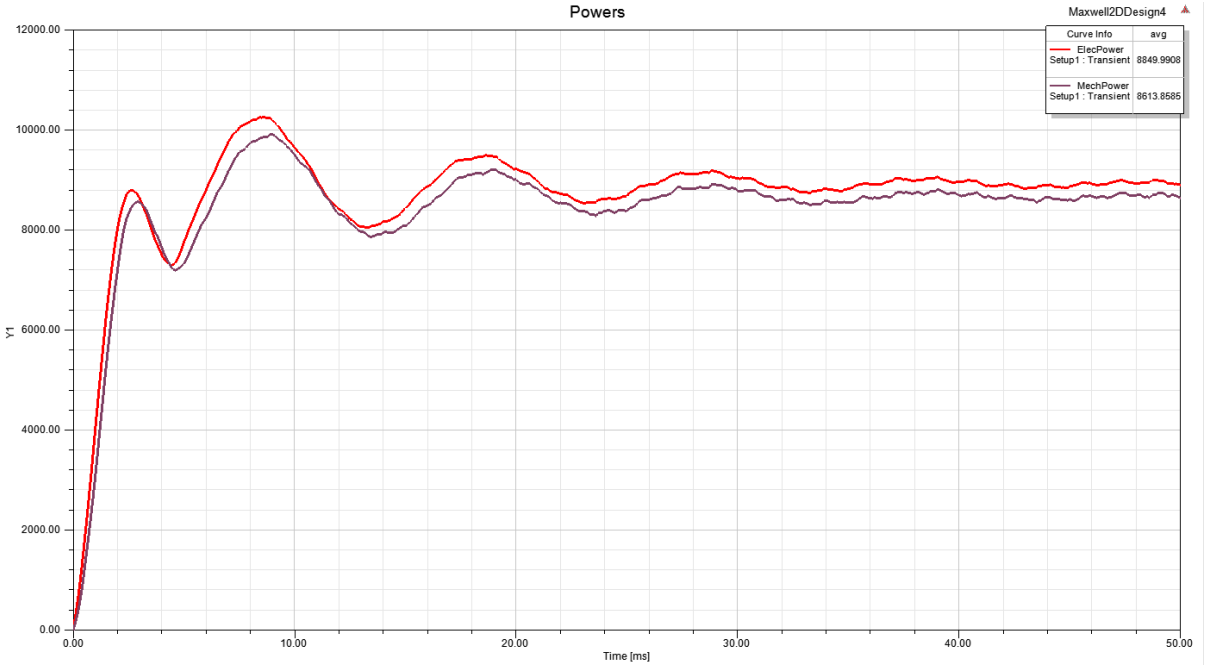

Figure 13

Figure… shows line currents at 8.5 kW 600 rpm. 19 Arms and 2 modules parallel. 9.5 Arms/module

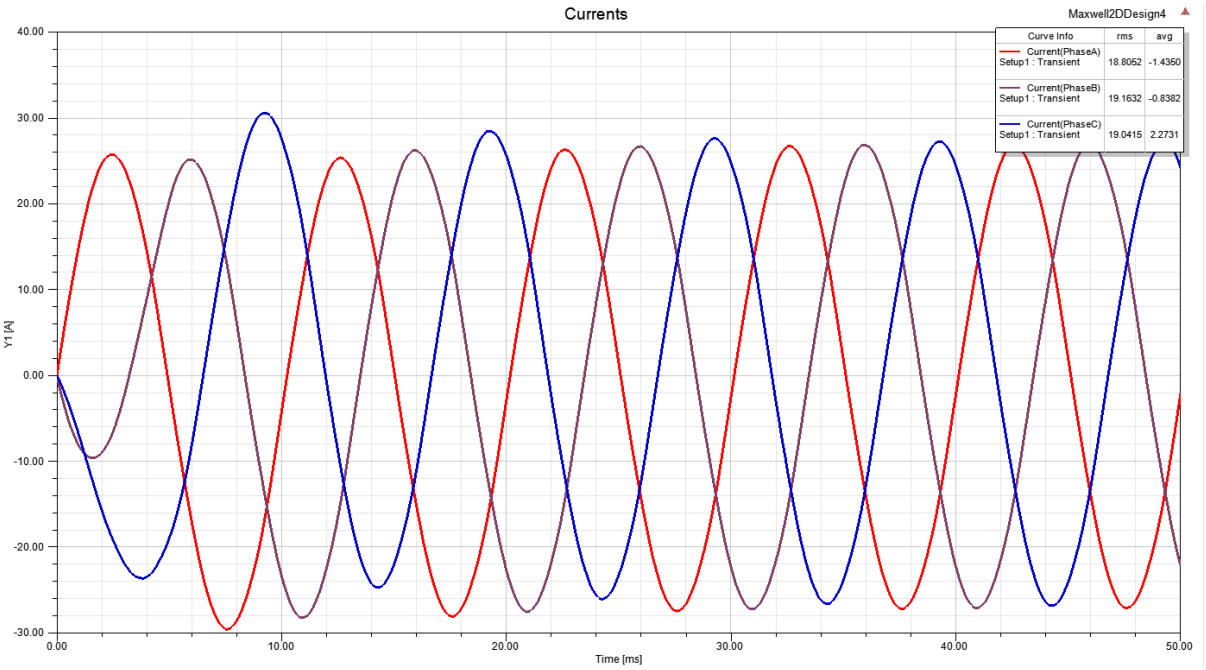

Figure 14

Figure… shws the output torque of the motor. **137 Nm.**

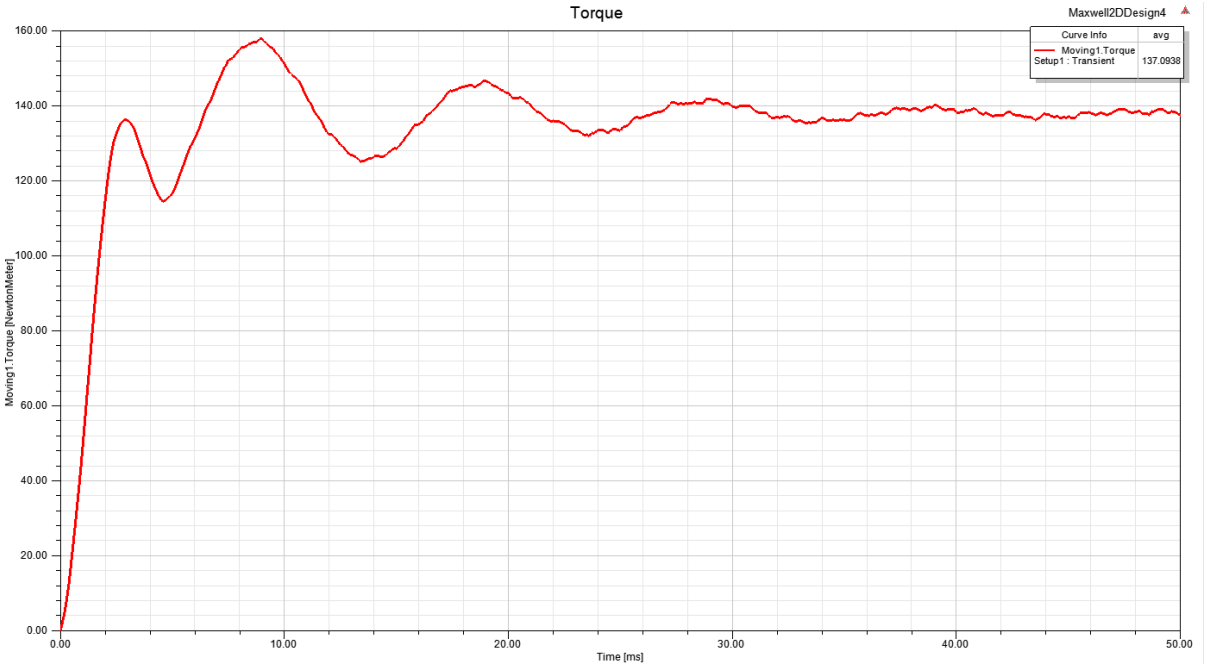

Figure 15

Figure… shows the torque ripple. Torque ripple is **1.25%** without stepped magnets.

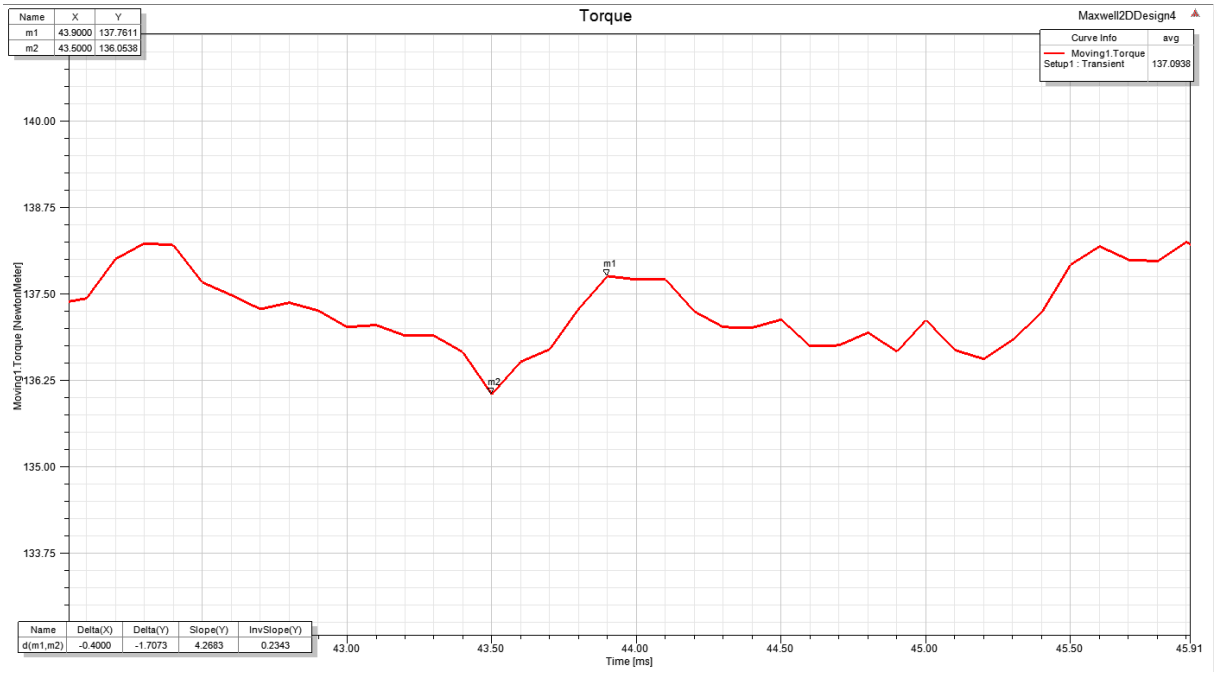

Figure 16

Figure… shows induced phase voltages. The target was 176 Vrms. However the simulation results shows it is 158 Vrms. It is decreased because of lower flux density is the teeth. Number of turns or magnet thickness should be increased.

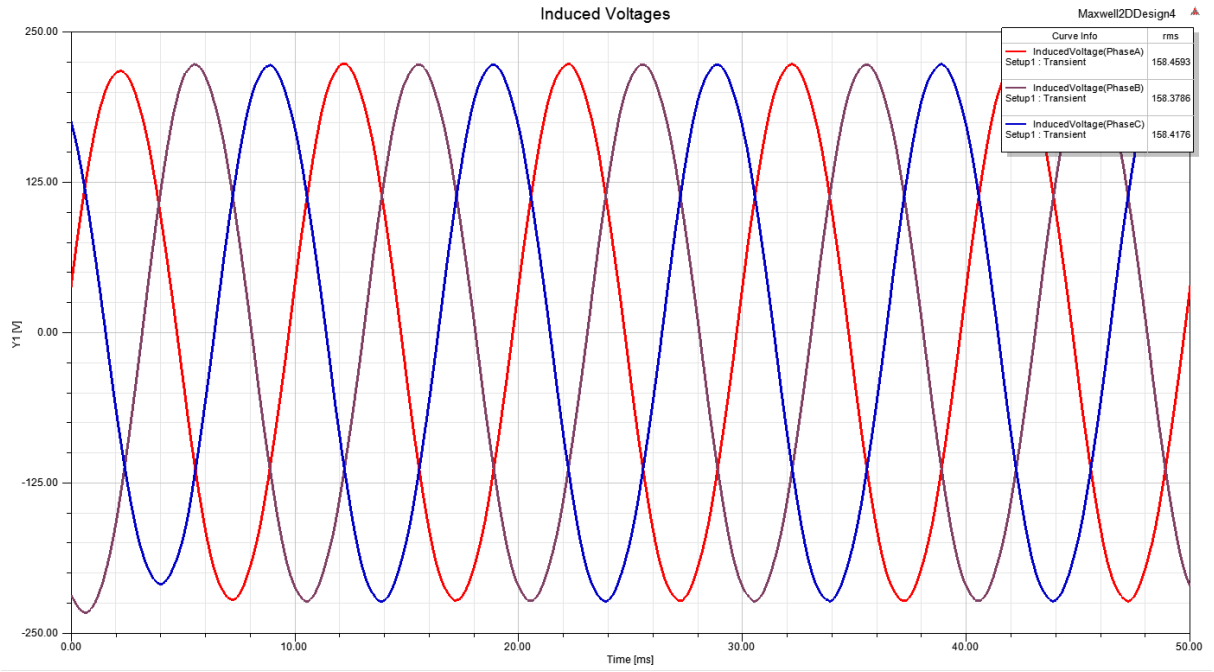

Figure 17

At 600 rpm (100Hz) 100 watt core loss.

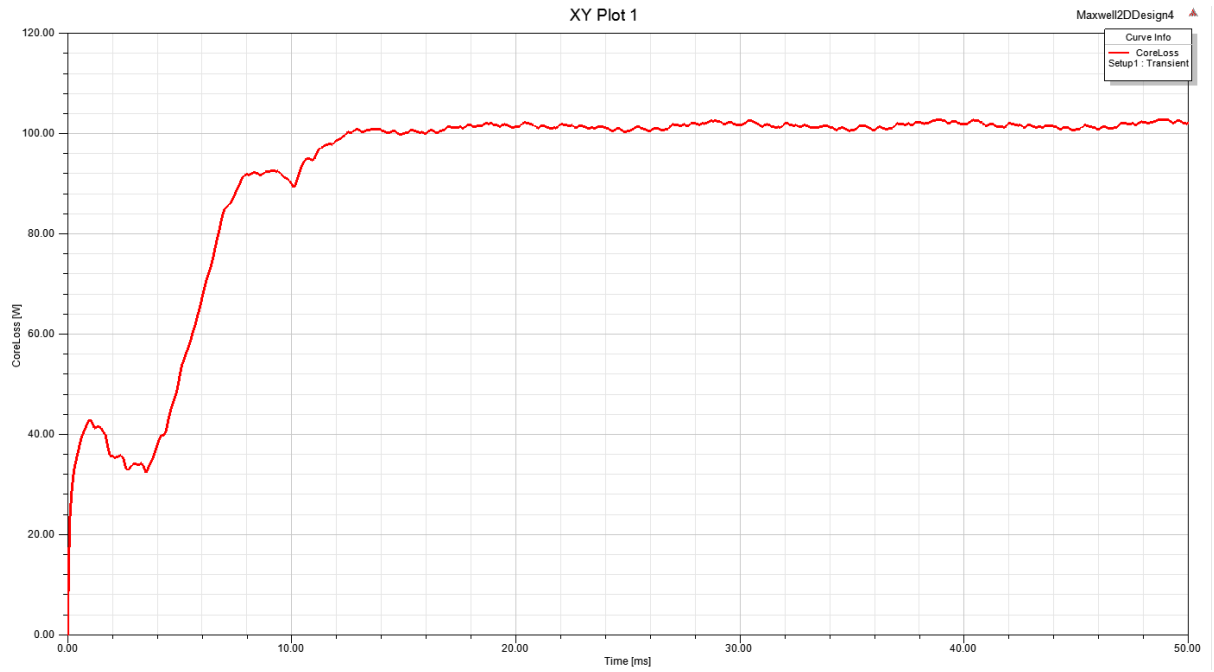

Figure 18

Flux distribution of the motor is given in figure…

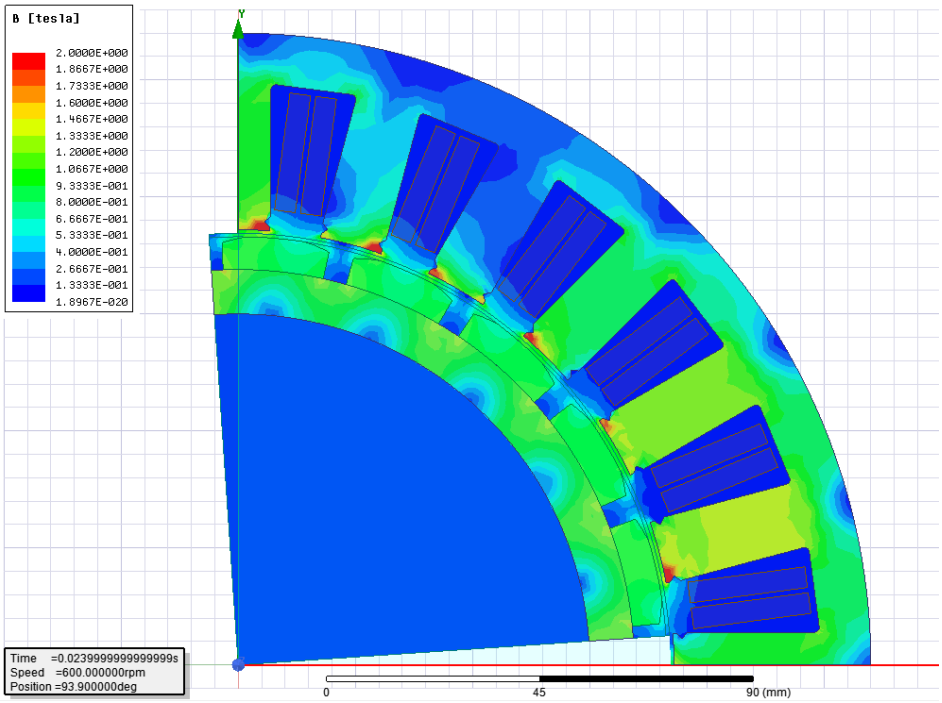

Figure 19

An origin centered curve is drawn from 0 to 90 degrees. Normal component of B vector is plotted in figure … while the motor rotates.

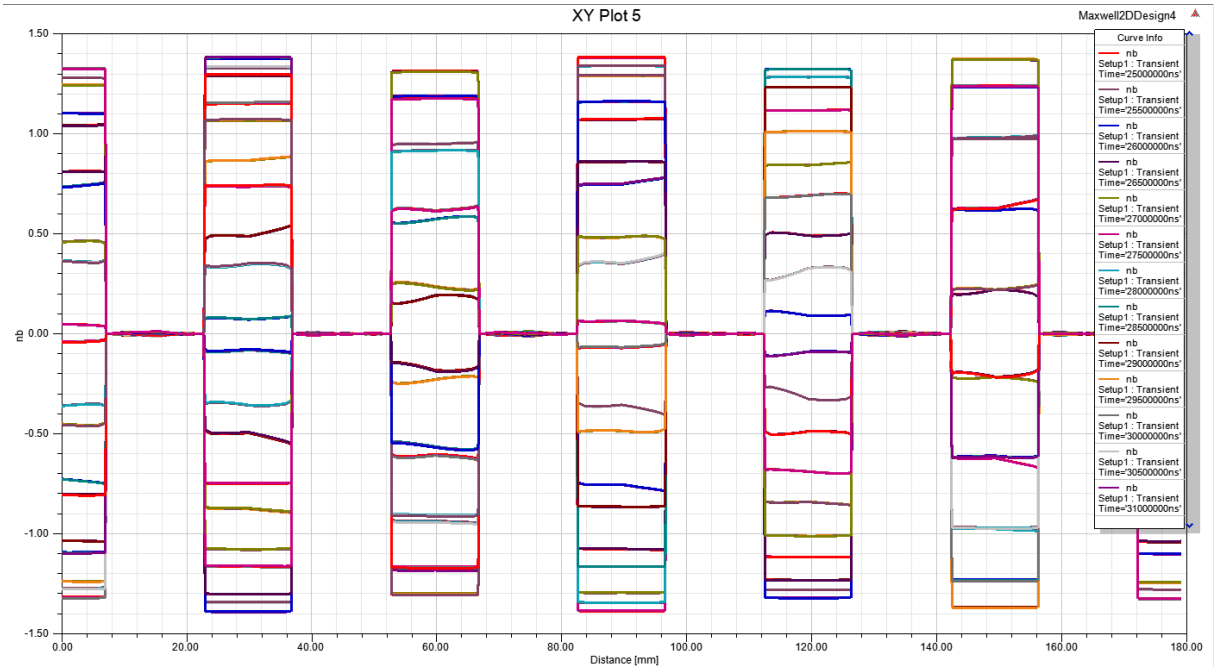

Figure 20

Maximum flux density is 1.45T in teeth. In Rmxpert, it was 1.65 T. However, magnet and teeth shape was not modified. Still, the difference is larger than I expected.

260 watt copper loss at 8.5 kW, 9.5 Arms/module. Figure… shows the copper loss.

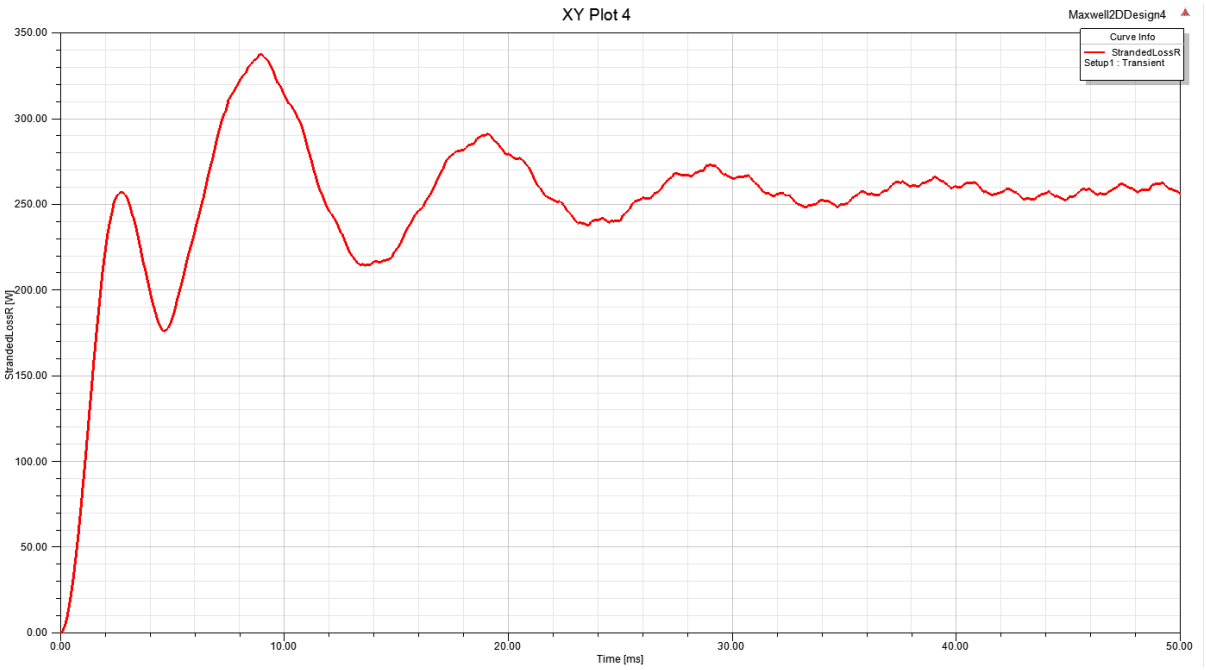

Figure 21

Overall efficiency is **96% @ 8.5 kW**. Windage and friction losses are not included.

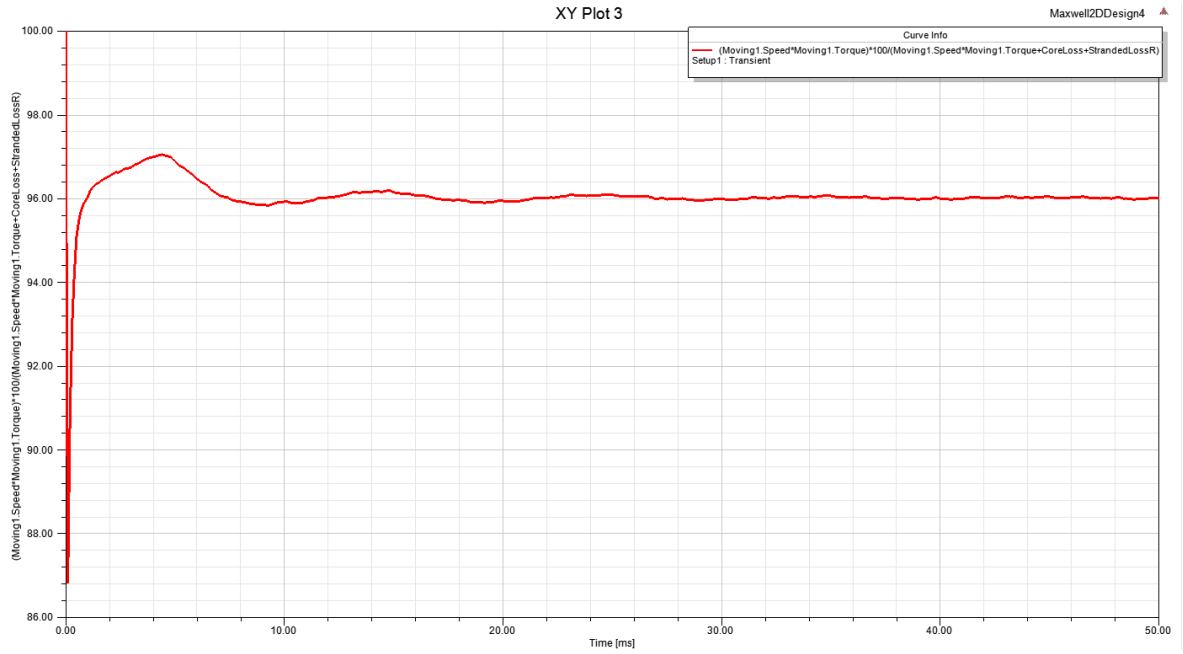

Figure 22

Design Summary

Motor Length	**140 mm**
Stator Outer Diameter	**270 mm**
Stator Inner Diameter	186 mm
Rotor Outer Diameter	183 mm
Rotor Inner Diameter	150 mm
Magnet Type	N45H
Magnet Thickness (max)	7 mm
Air Gap	**1.5 mm**
Wire Diameter	1.628 mm
Slot Fill Factor	**44.7 %**

Rated Power	**8.5 kW**
Rated Torque	137 Nm
Current Per Module	**9.5 Arms/Module**
Current Density	**4.56 A/mm^2**
Copper Loss	260 watt
Core Loss	100 watt
Phase Resistnce	0.237 ohm
Induced Voltage per Module per Phase @600	79 Vrms
Efficiency @ rated cond	**96 %**