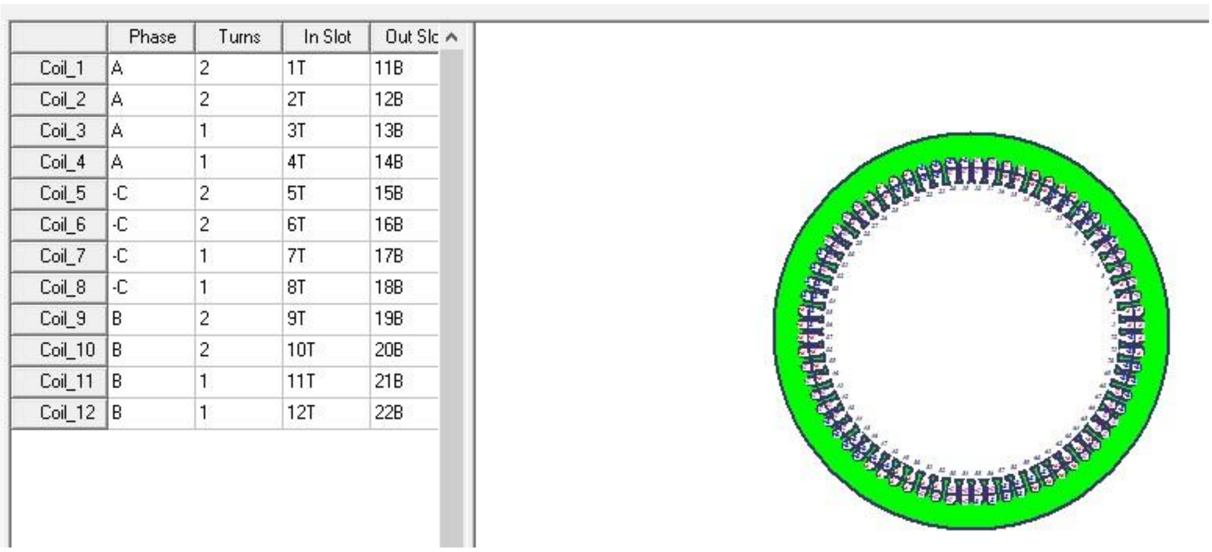
PROJECT-3 MAXWELL ANALYSIS OF MOTOR

Introduction

Designing a motor is an iterative process and optimization is the key to develop well-designed machines. In the beginning of Project-3,I started to fix my mistakes made at Project-2 design. They were stator windings and sizing of the slots of stator. I encountered these problems when I inserted my design parameters to MAXWELL Rmxprt. Why and how they are needed to fix are explained at my iphyton document in the rar file. After fixing opertion, i inserted my parameters to rmxprt and showed the results of rmxprt analysis. The outputs and corresponding comments are made at the below of each figure. After finishing rmxprt analysis, i analyse the motor at 2D design. By drawing polylines for stator yoke,stator tooth,rotor tooth,rotor yoke and airgap i showed the lines of the machine. Also, phase current and develop torque data are shown.

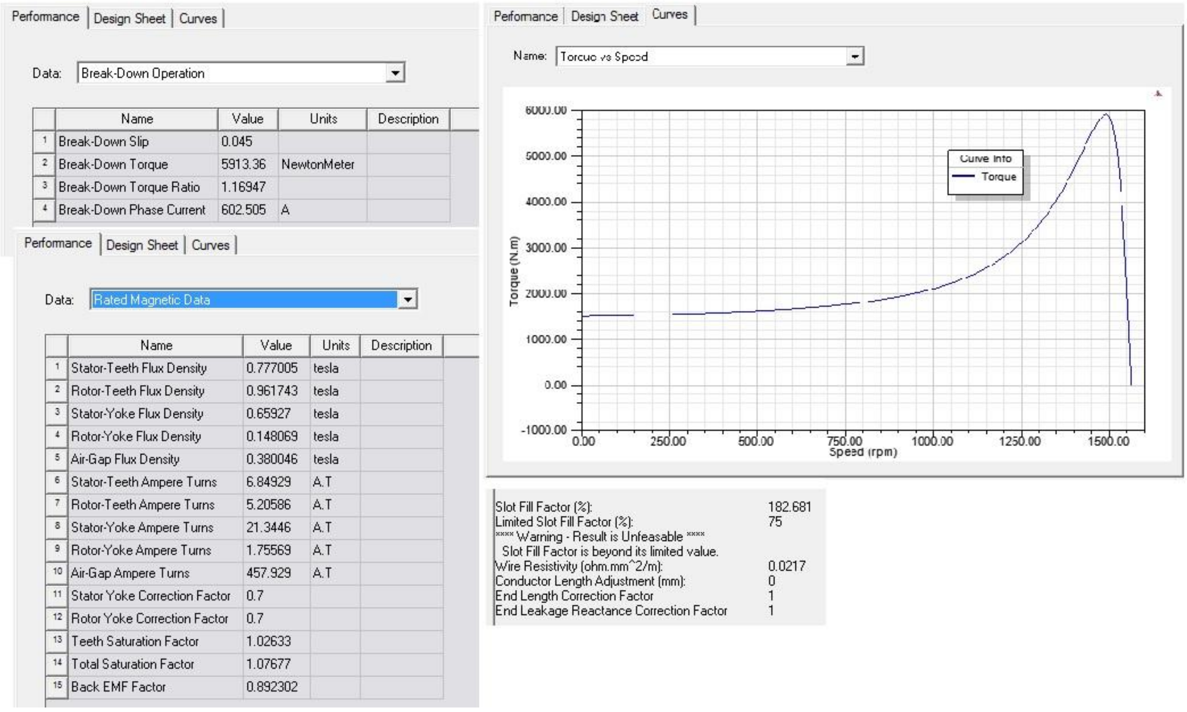
Correction of Mistakes from Project 2 (reachable from project3.iphynb)

While applying my project 2 winding configration to Maxwell, i saw that found zQ parameter and so corresponding stator number of slots are not accurate to apply to maxwell. One of them was my previous zQ parameter was rounded to 3 and found in that manner. The rounding of the zQ parameters cause my windings not to satisfy the accurate winding diagram. By doing this, i obtained below winding diagram which is wrong and which causes my airgap flux density not to reach the designed value that leads not to reach desired torque.



	Phase	Turns	In Slot	Out Slc
Coil_1	A	2	1T	11B
Coil_2	A	2	2T	12B
Coil_3	A	1	3T	13B
Coil_4	A	1	4T	14B
Coil_5	-C	2	5T	15B
Coil_6	-C	2	6T	16B
Coil_7	-C	1	7T	17B
Coil_8	-C	1	8T	18B
Coil_9	B	2	9T	19B
Coil_10	B	2	10T	20B
Coil_11	B	1	11T	21B
Coil_12	B	1	12T	22B

Figure 1- Wrong Stator Winding Configuration



Performance | Design Sheet | Curves

Data: Break-Down Operation

	Name	Value	Units	Description
1	Break-Down Slip	0.045		
2	Break-Down Torque	5913.36	NewtonMeter	
3	Break-Down Torque Ratio	1.16947		
4	Break-Down Phase Current	602.505	A	

Performance | Design Sheet | Curves

Data: Rated Magnetic Data

	Name	Value	Units	Description
1	Stator-Teeth Flux Density	0.777005	tesla	
2	Rotor-Teeth Flux Density	0.961743	tesla	
3	Stator-Yoke Flux Density	0.65927	tesla	
4	Rotor-Yoke Flux Density	0.148069	tesla	
5	Air-Gap Flux Density	0.380046	tesla	
6	Stator-Teeth Ampere Turns	6.84929	A.T	
7	Rotor-Teeth Ampere Turns	5.20586	A.T	
8	Stator-Yoke Ampere Turns	21.3446	A.T	
9	Rotor-Yoke Ampere Turns	1.75569	A.T	
10	Air-Gap Ampere Turns	457.929	A.T	
11	Stator Yoke Correction Factor	0.7		
12	Rotor Yoke Correction Factor	0.7		
13	Teeth Saturation Factor	1.02633		
14	Total Saturation Factor	1.07677		
15	Back EMF Factor	0.892302		

Slot Fill Factor (%):	182.681
Limited Slot Fill Factor (%):	75
**** Warning - Result is Unfeasable ****	
Slot Fill Factor is beyond its limited value.	
Wire Resistivity (ohm.mm^2/m):	0.0217
Conductor Length Adjustment (mm):	0
End Length Correction Factor	1
End Leakage Reactance Correction Factor	1

Figure 2-Result of wrong winding configuration

It should be corrected, that zQ parameter will be integer and even number.It is obviously seen that because of that winding configuration mistake the airgap flux density can't reach the desired parameter which causes the motor not to develop required rated torque level. Also, the slot fillness is far away from optimum design after correcting the winding data, it will be checked again.

Depending on the formula of zQ, zQ will be integer and even. This leads to change,a which is number of parallel paths,Ns which is the number of the coil turns in series in a phase winding.

(zQ=(2*a*m*Ns)/Qs_4spp)

a=2, and to obtain zQ as 6 which leads to change Ns from 32 to 36...

Depending on the correcting data, formula is applied as below.

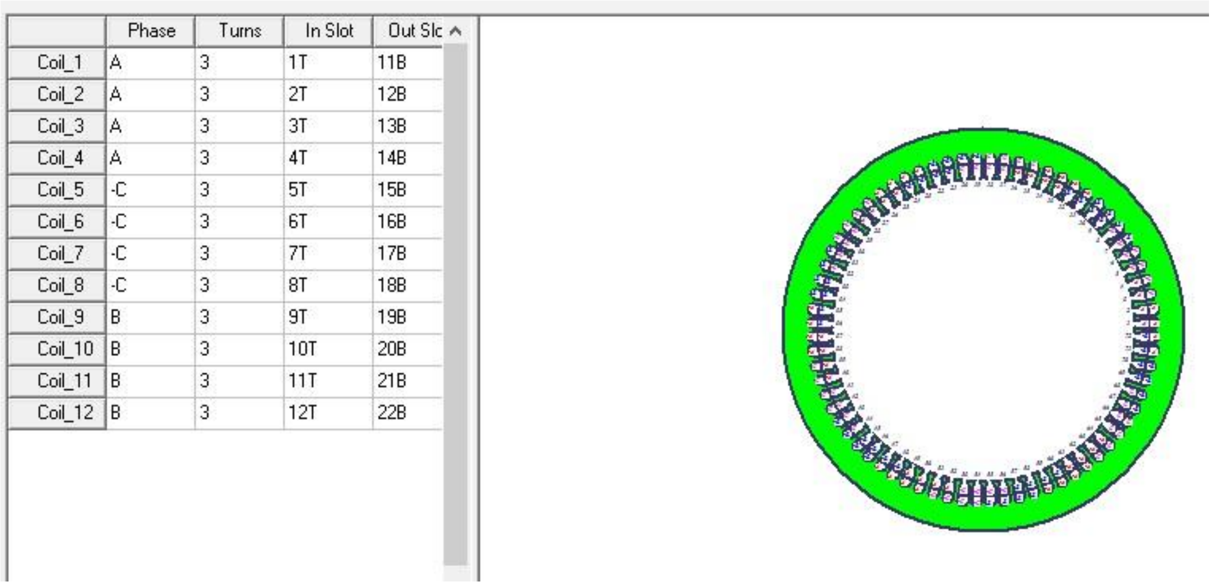
```
In [303]: a=2;#parallel paths
          zQ_project3_try=(2*a*m*Ns)/Qs_4spp
          print 'The number of conductors per slot= ',zQ_project3_try,'.'

          The number of conductors per slot=  6.0 .

In [304]: a_prjct3=2;#parallel paths
          Ns_prjct3=36;
          zQ_prjct3=(2*a_prjct3*m*Ns_prjct3)/Qs_4spp
          print 'The number of conductors per slot= ',zQ_prjct3,'.'
          #To change number of parallel paths to 2 is not enough, problem leaded to change Ns from 32 to 36.

          The number of conductors per slot=  6 .
```

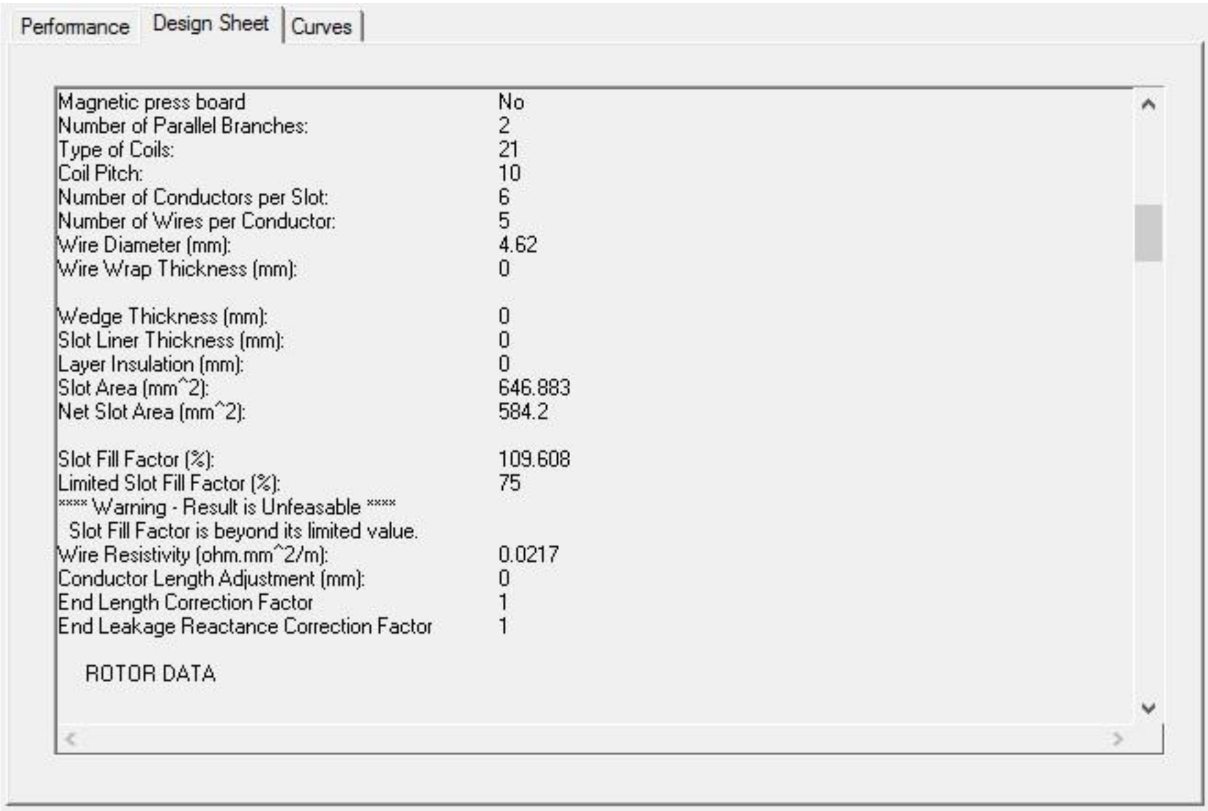
By adding the parallel winding paths to stator, the stator conductor area was changed. the stator conductor area was changed from 176 to 88.4518417312 in units of mm2.



	Phase	Turns	In Slot	Out Slc
Coil_1	A	3	1T	11B
Coil_2	A	3	2T	12B
Coil_3	A	3	3T	13B
Coil_4	A	3	4T	14B
Coil_5	-C	3	5T	15B
Coil_6	-C	3	6T	16B
Coil_7	-C	3	7T	17B
Coil_8	-C	3	8T	18B
Coil_9	B	3	9T	19B
Coil_10	B	3	10T	20B
Coil_11	B	3	11T	21B
Coil_12	B	3	12T	22B

Figure 3-Fixed winding configuration

By entering as, Number of parallel paths =2 , Conductors per slot =6 , the winding turns equalized and winding distribution are reformed. According to changes the rmxprt was shown below.



Performance | Design Sheet | Curves

Magnetic press board	No
Number of Parallel Branches:	2
Type of Coils:	21
Coil Pitch:	10
Number of Conductors per Slot:	6
Number of Wires per Conductor:	5
Wire Diameter (mm):	4.62
Wire Wrap Thickness (mm):	0
Wedge Thickness (mm):	0
Slot Liner Thickness (mm):	0
Layer Insulation (mm):	0
Slot Area (mm^2):	646.883
Net Slot Area (mm^2):	584.2
Slot Fill Factor (%):	109.608
Limited Slot Fill Factor (%):	75
**** Warning - Result is Unfeasable ****	
Slot Fill Factor is beyond its limited value.	
Wire Resistivity (ohm.mm^2/m):	0.0217
Conductor Length Adjustment (mm):	0
End Length Correction Factor	1
End Leakage Reactance Correction Factor	1

ROTOR DATA

Figure4-Wrong slot shapes

The slot dimensions are not accurate. Therefore, it should be increase to obtain at least %75 slot fill factor.Another parameter to be changed is b1 value of the stator slot. It is too high by considering the general design criteria for design handout from Ionboldea's book.

b1,h2,h3,h6 was changed and the changeds resulted changing of hs,h5,b4c,b5c,h4.

End length,End ring width,end ring height,end ring conductor type calculations are also added which weren't calculated for project2.

Inserting of Rmxprt Design parameters

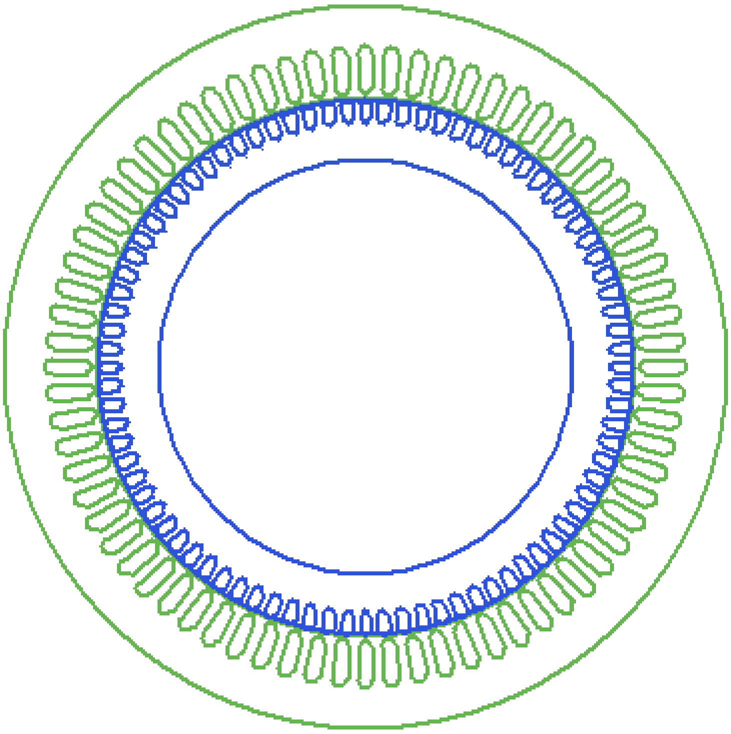


Figure 5– Machine figure

Machine

	Name	Value	Unit	Evaluated Value	Description	Rea
	Machine Type	Three Phase Induction Motor				
	Number of Poles	6			Number of poles of the ...	
	Stray Loss Factor	0.01		0.01	Stray Loss Factor	
	Frictional Loss	150	W	150W	The frictional loss meas...	
	Windage Loss	0	W	0W	The windage loss meas...	
	Reference Speed	1520	rpm		The reference speed at...	

Show Hidden

Figure 6– Machine Parameters

Stator

	Name	Value	Unit	Evaluated Value	Description	Read-only
	Outer Diameter	830	mm	830mm	Outer diameter of the st...	☐
	Inner Diameter	620	mm	620mm	Inner diameter of the st...	☐
	Length	438.68	mm	438.68mm	Length of the stator core	☐
	Stacking Factor	0.95			Stacking factor of the s...	☐
	Steel Type	steel_1008			Steel type of the stator ...	☐
	Number of Slots	72			Number of slots of the s...	☐
	Slot Type	1			Slot type of the stator c...	☐
	Lamination Sectors	0			Number of lamination s...	☐
	Press Board Thickness	0	mm		Magnetic press board t...	☐
	Skew Width	0		0	Skew width measured i...	☐

Figure 7-Stator parameters

Slot

	Name	Value	Unit	Evaluated Value	Description	Read-only
	Auto Design	☐			Auto design Hs2, Bs1 a...	☐
	Parallel Tooth	☑			Design Bs1 and Bs2 ba...	☐
	Tooth Width	12.0764	mm	12.0764mm	Tooth width for parallel ...	☐
	Hs0	2	mm	2mm	Slot dimension: Hs0	☐
	Hs2	39.71	mm	39.71mm	Slot dimension: Hs2	☐
	Bs0	2	mm	2mm	Slot dimension: Bs0	☐

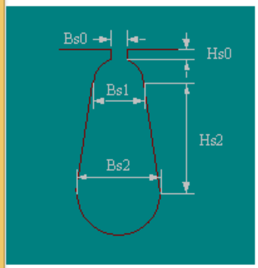


Figure 8-Slot parameters

	Phase	Turns	In Slot	Out Slc
Coil_1	A	3	1T	11B
Coil_2	A	3	2T	12B
Coil_3	A	3	3T	13B
Coil_4	A	3	4T	14B
Coil_5	-C	3	5T	15B
Coil_6	-C	3	6T	16B
Coil_7	-C	3	7T	17B
Coil_8	-C	3	8T	18B
Coil_9	B	3	9T	19B
Coil_10	B	3	10T	20B
Coil_11	B	3	11T	21B
Coil_12	B	3	12T	22B

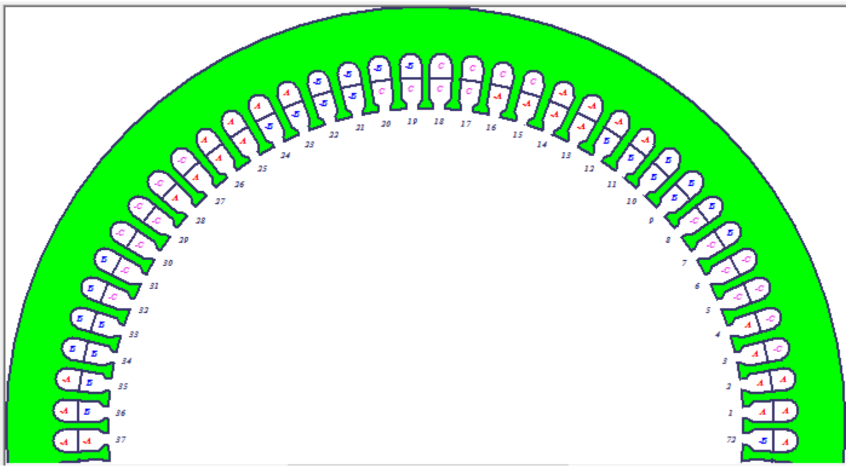


Figure 9-Slot Windings

Rotor

Name	Value	Unit	Evaluated Value	Description	Read-only
Stacking Factor	0.95			Stacking factor of the rotor core	☐
Number of Slots	84			Number of slots of the rotor core	☐
Slot Type	3			Slot type of the rotor core	☐
Outer Diameter	616.136	mm	616.136mm	Outer diameter of the rotor core	☐
Inner Diameter	480.28	mm	480.28mm	Inner diameter of the rotor core	☐
Length	438.68	mm	438.68mm	Length of the rotor core	☐
Steel Type	steel_1008			Steel type of the rotor core	☐
Skew Width	1		1	Skew width measured in slot number	☐
Cast Rotor	☑			Rotor squirrel-cage winding is cast	☐
Half Slot	☐			Half-shaped slot (un-symmetric)	☐
Double Cage	☐			Double-squirrel-cage winding	☐

☐ Show Hidden

Figure 10-Rotor Parameters

Slot

Name	Value	Unit	Evaluated Value	Description	Read-only
Hs0	2	mm	2mm	Slot dimension: Hs0	☐
Hs01	0	mm	0mm	Slot dimension: Hs01	☐
Hs1	3.5	mm	3.5mm	Slot dimension: Hs1	☐
Hs2	17.78	mm	17.78mm	Slot dimension: Hs2	☐
Bs0	2.5	mm	2.5mm	Slot dimension: Bs0	☐
Bs1	14.569	mm	14.569mm	Slot dimension: Bs1	☐
Bs2	12.29	mm	12.29mm	Slot dimension: Bs2	☐
Rs	6	mm	6mm	Slot dimension: Rs	☐

Figure 11-Rotor Slot Parameters

Winding

Name	Value	Unit	Evaluated Value	Description
Bar Conductor Type	aluminum			Select bar conductors Type
End Length	22.59	mm	22.59mm	Single-side end extended bar length
End Ring Width	59.91	mm	59.91mm	One-side width of end rings (in axial direction)
End Ring Height	12	mm	12mm	Height of end rings (in radian direction)
End Ring Conductor Type	aluminum			Select End ring conductor Type

Figure 12-Rotor Endring Parameters

Maxwell Rmxprt Design

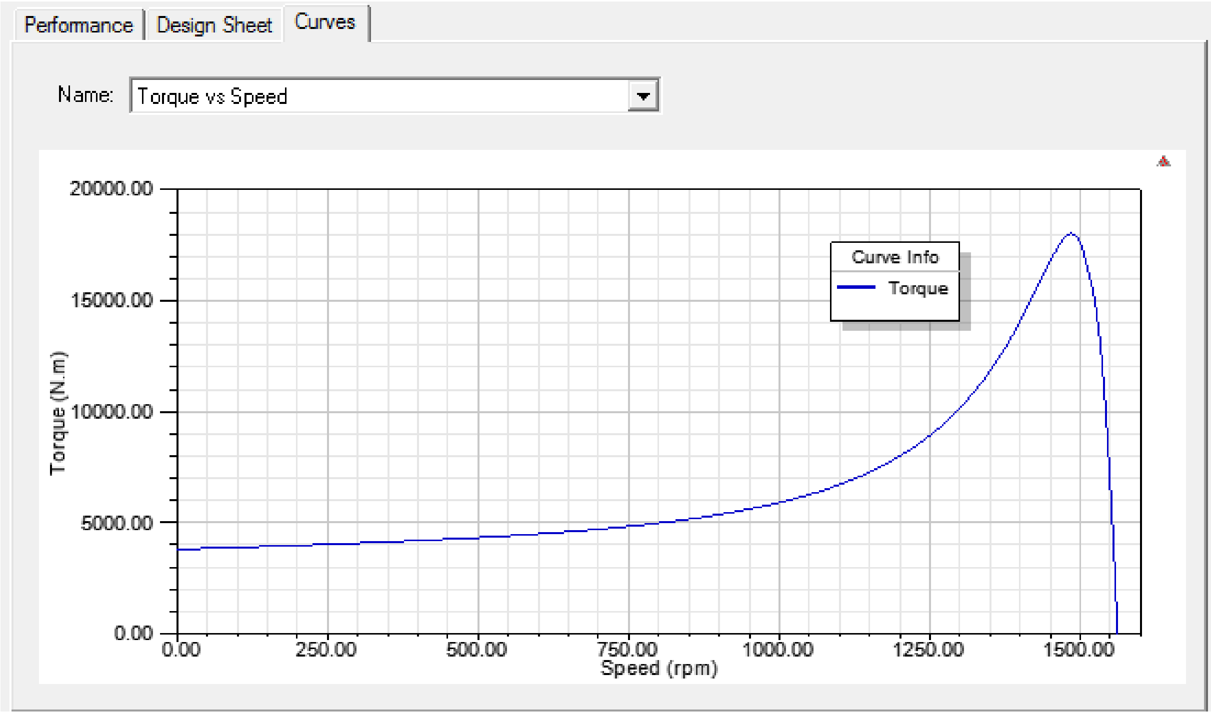


Figure 13-Torque vs Speed Characteristic

Performance | Design Sheet | Curves

Data: Rated Performance

	Name	Value	Units	Description
1	Stator Ohmic Loss	9313.8	W	
2	Rotor Ohmic Loss	12107.6	W	
3	Iron-Core Loss	0.286484	W	
4	Frictional and Windage Loss	152.504	W	
5	Stray Loss	12800	W	
6	Total Loss	34374.2	W	
7	Output Power	1279550	W	
8	Input Power	1313930	W	
9	Efficiency	97.3839	%	
10	Power Factor	0.87758		
11	Rated Torque	7906.7	NewtonMeter	
12	Rated Speed	1545.38	rpm	
13	Rated Slip	0.00937252		

Figure 14-Rated Performance of motor

We can obviously see that the motor can deliver rated torque 7906Nm at rated speed.
Efficiency of motor is 97 and power factor is 0.88

Performance | Design Sheet | Curves

Data: Rated Magnetic Data

	Name	Value	Units	Description
1	Stator-Teeth Flux Density	1.5346	tesla	
2	Rotor-Teeth Flux Density	1.86161	tesla	
3	Stator-Yoke Flux Density	1.58282	tesla	
4	Rotor-Yoke Flux Density	1.90786	tesla	
5	Air-Gap Flux Density	0.650798	tesla	
6	Stator-Teeth Ampere Turns	105.556	A.T	
7	Rotor-Teeth Ampere Turns	270.401	A.T	
8	Stator-Yoke Ampere Turns	181.403	A.T	
9	Rotor-Yoke Ampere Turns	524.964	A.T	
10	Air-Gap Ampere Turns	1048.37	A.T	
11	Stator Yoke Correction Factor	0.304957		
12	Rotor Yoke Correction Factor	0.237101		
13	Teeth Saturation Factor	1.35861		
14	Total Saturation Factor	2.03238		
15	Back EMF Factor	0.933986		

Figure 15-Rated Magnetic Data of motor

Depending on my calculations, i had found the airgap flux density as below at my iphyton file.

- The new air-gap flux density= 0.680387811665 in units of T. The rated magnetic data shows that it is 0.6507, which shows that analytic design is nearly accurate to simulation.

Table 6.2 Permitted flux densities of the magnetic circuit for various standard electrical machines

	Flux density B[T]			
	Asynchronous machines	Salient-pole synchronous machines	Nonsalient-pole synchronous machines	DC machines
Air gap	0.7–0.9 ($\hat{B}_{\delta 1}$)	0.85–1.05 ($\hat{B}_{\delta 1}$)	0.8–1.05 ($\hat{B}_{\delta 1}$)	0.6–1.1 (B_{max})
Stator yoke	1.4–1.7 (... 2)	1.0–1.5	1.1–1.5	1.1–1.5
Tooth (apparent maximum value)	1.4–2.1 (stator) 1.5–2.2 (rotor)	1.6–2.0	1.5–2.0	1.6–2.0 (compensating winding) 1.8–2.2 (armature winding)
Rotor yoke	1–1.6 (... 1.9)	1.0–1.5	1.3–1.6	1.0–1.5
Pole core	–	1.3–1.8	1.1–1.7	1.2–1.7
Commutating poles	–	–	–	1.3

Table 1-Flux densities of the motor

The above flux densities taken from the textbook are aimed to reach at design of the motor. At my design, stator yoke flux density seems high and aimed airgap flux density is low at my design. I might have increased the stator yoke height of the machine to reduce the stator yoke flux density, but it would reduce my starting torque capacity.

Rmxprt Design Sheet Output

Three-Phase Induction Machine Design

File: Setup1.res

GENERAL DATA

Given Output Power (kW): 1280
Rated Voltage (V): 1350
Winding Connection: Wye
Number of Poles: 6
Given Speed (rpm): 1520
Frequency (Hz): 78
Stray Loss (W): 12800
Frictional Loss (W): 150
Windage Loss (W): 0
Operation Mode: Motor
Type of Load: Constant Power
Operating Temperature (C): 75

STATOR DATA

Number of Stator Slots: 72
Outer Diameter of Stator (mm): 830
Inner Diameter of Stator (mm): 620

Type of Stator Slot: 1
Stator Slot

hs0 (mm):	2
hs2 (mm):	39.71
bs0 (mm):	2
bs1 (mm):	15.8425
bs2 (mm):	19.3101

Top Tooth Width (mm): 12.0764
Bottom Tooth Width (mm): 12.0764

Length of Stator Core (mm): 438.68
Stacking Factor of Stator Core: 0.95
Type of Steel: steel_1008
Number of lamination sectors 0
Press board thickness (mm): 0
Magnetic press board No
Number of Parallel Branches: 2
Type of Coils: 21
Coil Pitch: 10
Number of Conductors per Slot: 6
Number of Wires per Conductor: 5
Wire Diameter (mm): 4.62
Wire Wrap Thickness (mm): 0

Wedge Thickness (mm): 0
Slot Liner Thickness (mm): 0
Layer Insulation (mm): 0
Slot Area (mm^2): 946.863
Net Slot Area (mm^2): 870.146

Slot Fill Factor (%): 73.589
Limited Slot Fill Factor (%): 75
Wire Resistivity (ohm.mm^2/m): 0.0217
Conductor Length Adjustment (mm): 0
End Length Correction Factor 1
End Leakage Reactance Correction Factor 1

ROTOR DATA

Number of Rotor Slots: 84
Air Gap (mm): 1.932
Inner Diameter of Rotor (mm): 480.28
Type of Rotor Slot: 3
Rotor Slot

hs0 (mm):	2
hs1 (mm):	3.5
hs2 (mm):	17.78
bs0 (mm):	2.5
bs1 (mm):	14.569
bs2 (mm):	12.29
rs (mm):	6

Cast Rotor: Yes
Half Slot: No

Length of Rotor (mm): 438.68
Stacking Factor of Rotor Core: 0.95
Type of Steel: steel_1008
Skew Width: 1
End Length of Bar (mm): 22.59
Height of End Ring (mm): 12
Width of End Ring (mm): 59.91
Resistivity of Rotor Bar
at 75 Centigrade (ohm.mm^2/m): 0.0263158
Resistivity of Rotor Ring
at 75 Centigrade (ohm.mm^2/m): 0.0263158
Magnetic Shaft:No

MATERIAL CONSUMPTION

Armature Copper Density (kg/m^3): 8900
Rotor Bar Material Density (kg/m^3): 2689
Rotor Ring Material Density (kg/m^3): 2689
Armature Core Steel Density (kg/m^3): 7872
Rotor Core Steel Density (kg/m^3): 7872

Armature Copper Weight (kg): 267.009
Rotor Bar Material Weight (kg): 36.2781
Rotor Ring Material Weight (kg): 7.28955
Armature Core Steel Weight (kg): 560.92
Rotor Core Steel Weight (kg): 292.324
Total Net Weight (kg): 1163.82

Armature Core Steel Consumption (kg): 1288.7
Rotor Core Steel Consumption (kg): 987.685

RATED-LOAD OPERATION

Stator Resistance (ohm): 0.00772194
Stator Resistance at 20C (ohm):0.00635192
Stator Leakage Reactance (ohm): 0.17581
Rotor Resistance (ohm): 0.0113345
Rotor Resistance at 20C (ohm): 0.00932354
Rotor Leakage Reactance (ohm): 0.160697
Resistance Corresponding to
Iron-Core Loss (ohm): 5.54943e+006
Magnetizing Reactance (ohm): 4.86019

Stator Phase Current (A): 634.073
Current Corresponding to
Iron-Core Loss (A): 0.000131179
Magnetizing Current (A): 149.782
Rotor Phase Current (A): 596.714

Copper Loss of Stator Winding (W): 9313.8
Copper Loss of Rotor Winding (W): 12107.6
Iron-Core Loss (W): 0.286484
Frictional and Windage Loss (W): 152.504
Stray Loss (W): 12800
Total Loss (W): 34374.2
Input Power (kW): 1313.93
Output Power (kW): 1279.55

Mechanical Shaft Torque (N.m): 7906.7
Efficiency (%): 97.3839
Power Factor: 0.87758
Rated Slip: 0.00937252
Rated Shaft Speed (rpm): 1545.38

NO-LOAD OPERATION

No-Load Stator Resistance (ohm): 0.00772194
No-Load Stator Leakage Reactance (ohm): 0.178953
No-Load Rotor Resistance (ohm): 0.0113328
No-Load Rotor Leakage Reactance (ohm): 0.162357

No-Load Stator Phase Current (A): 154.674
No-Load Iron-Core Loss (W): 0.305497
No-Load Input Power (W): 14723.7
No-Load Power Factor: 0.00531908
No-Load Slip: 9.15285e-006
No-Load Shaft Speed (rpm): 1559.99

BREAK-DOWN OPERATION

Break-Down Slip: 0.05
Break-Down Torque (N.m): 17972.6
Break-Down Torque Ratio: 2.27309
Break-Down Phase Current (A): 2134.72

LOCKED-ROTOR OPERATION

Locked-Rotor Torque (N.m): 3819.57
Locked-Rotor Phase Current (A): 3140.24
Locked-Rotor Torque Ratio: 0.48308
Locked-Rotor Current Ratio: 4.95249

Locked-Rotor Stator Resistance (ohm): 0.00772194
Locked-Rotor Stator
Leakage Reactance (ohm): 0.133407
Locked-Rotor Rotor Resistance (ohm): 0.0221143
Locked-Rotor Rotor
Leakage Reactance (ohm): 0.115716

DETAILED DATA AT RATED OPERATION

Stator Slot Leakage Reactance (ohm): 0.124187
Stator End-Winding Leakage
Reactance (ohm): 0.0273096
Stator Differential Leakage
Reactance (ohm): 0.0243101
Rotor Slot Leakage Reactance (ohm): 0.104425
Rotor End-Winding Leakage
Reactance (ohm): 0.0222952
Rotor Differential Leakage
Reactance (ohm): 0.0238248
Skewing Leakage Reactance (ohm): 0.0101505

Stator Winding Factor: 0.925031

Stator-Teeth Flux Density (Tesla): 1.5346
Rotor-Teeth Flux Density (Tesla): 1.86161
Stator-Yoke Flux Density (Tesla): 1.58282
Rotor-Yoke Flux Density (Tesla): 1.90786
Air-Gap Flux Density (Tesla): 0.650798

Stator-Teeth Ampere Turns (A.T): 105.556
Rotor-Teeth Ampere Turns (A.T): 270.401
Stator-Yoke Ampere Turns (A.T): 181.403
Rotor-Yoke Ampere Turns (A.T): 524.964
Air-Gap Ampere Turns (A.T): 1048.37

Correction Factor for Magnetic
Circuit Length of Stator Yoke: 0.304957
Correction Factor for Magnetic
Circuit Length of Rotor Yoke: 0.237101
Saturation Factor for Teeth: 1.35861
Saturation Factor for Teeth & Yoke: 2.03238
Induced-Voltage Factor: 0.933987

Stator Current Density (A/mm^2): 3.78238
Specific Electric Loading (A/mm): 70.3156
Stator Thermal Load (A^2/mm^3): 265.961

Rotor Bar Current Density (A/mm^2): 4.27606
Rotor Ring Current Density (A/mm^2): 8.81672

Half-Turn Length of
Stator Winding (mm): 828.53

WINDING ARRANGEMENT

The 3-phase, 2-layer winding can be arranged in 24 slots as below:

AAAAZZZZBBBBXXXXCCCCYYYY

Angle per slot (elec. degrees): 15

Phase-A axis (elec. degrees): 97.5
First slot center (elec. degrees): 0

TRANSIENT FEA INPUT DATA

For one phase of the Stator Winding:
  Number of Turns: 72
  Parallel Branches: 2
  Terminal Resistance (ohm): 0.00772194
  End Leakage Inductance (H): 5.57238e-005
For Rotor End Ring Between Two Bars of One Side:
  Equivalent Ring Resistance (ohm): 9.11644e-007
  Equivalent Ring Inductance (H): 1.04569e-008
2D Equivalent Value:
  Equivalent Model Depth (mm): 438.68
  Equivalent Stator Stacking Factor: 0.95
  Equivalent Rotor Stacking Factor: 0.95
Estimated Rotor Inertial Moment (kg m^2): 48.4115

Maxwell 2D Design

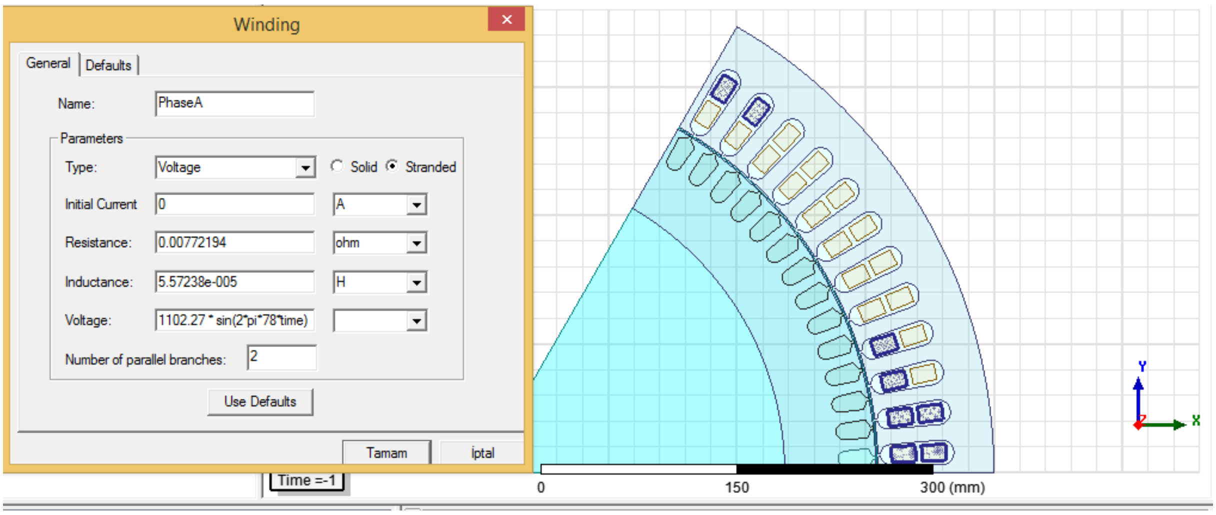


Figure 16-Phase A properties

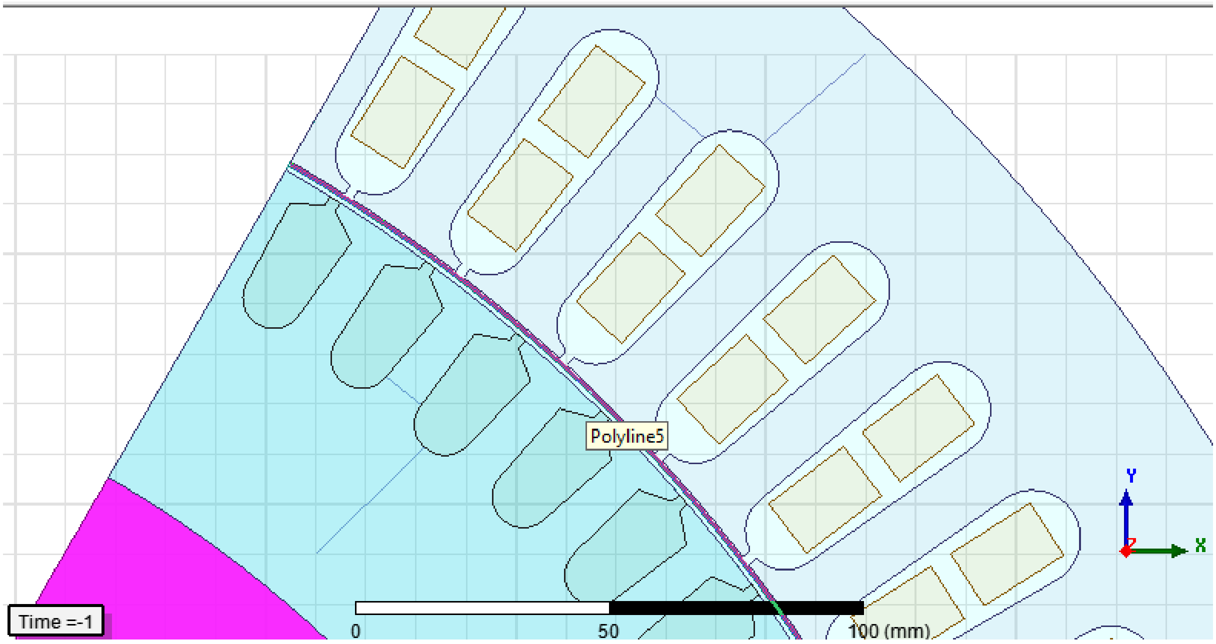


Figure 17- Stator Yoke, Stator Teeth,Rotor Teeth,Rotor Yoke and Airgap polylines

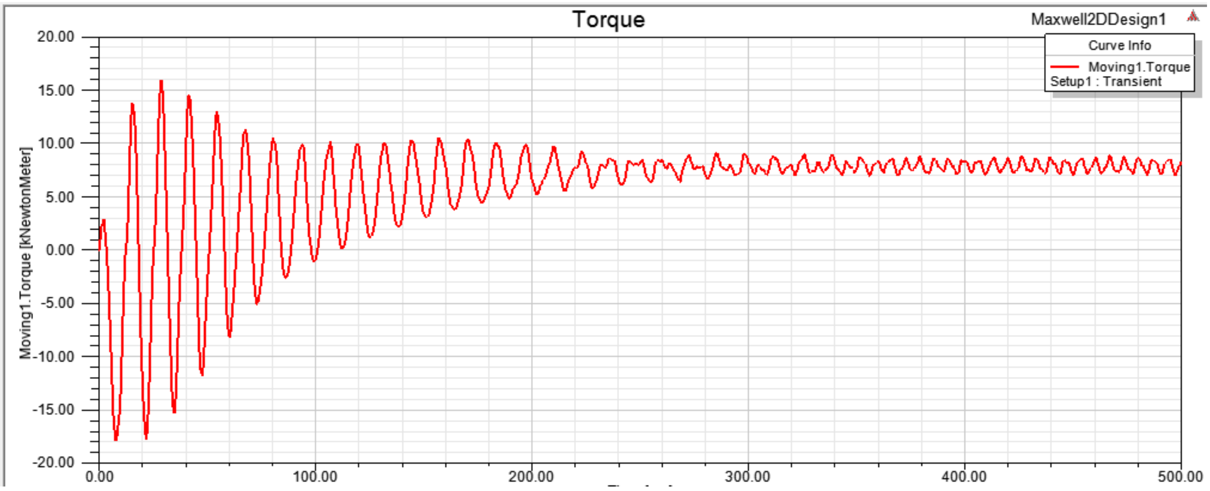


Figure 18-Moving Torque

Torque ripple is low as 1400Nm.

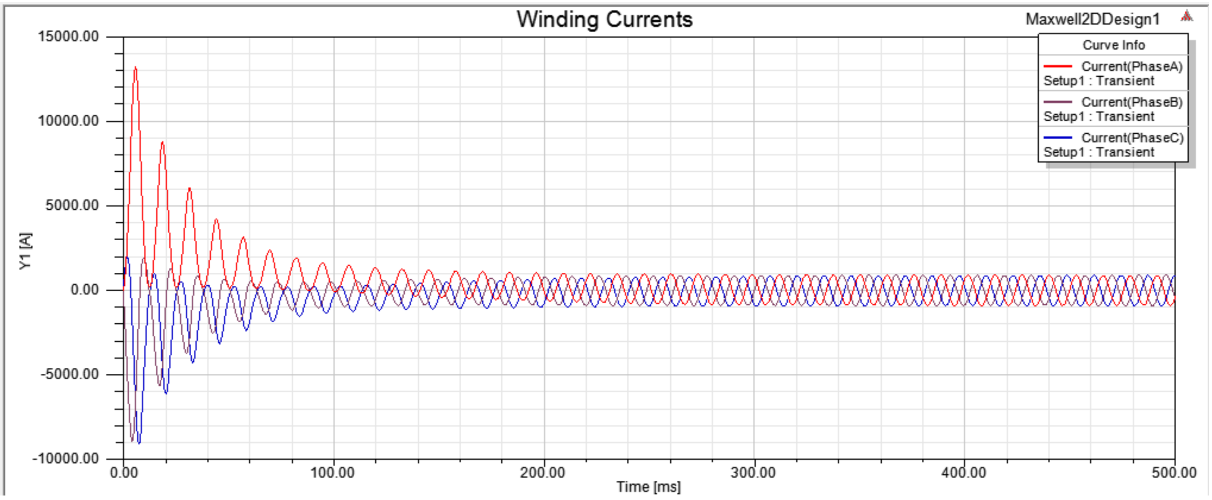


Figure 19- Phase Currents

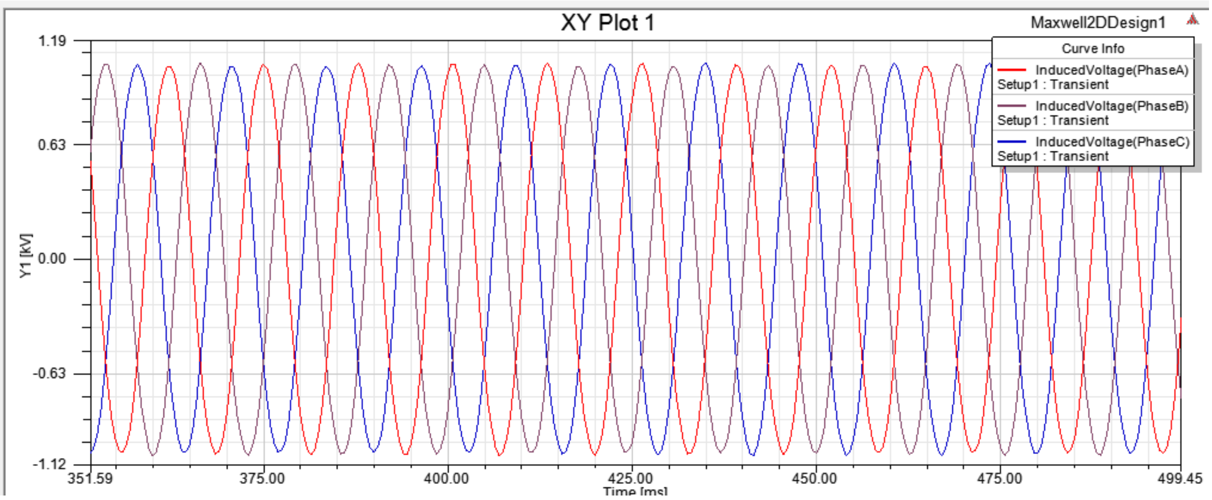


Figure 20-Induced Voltages

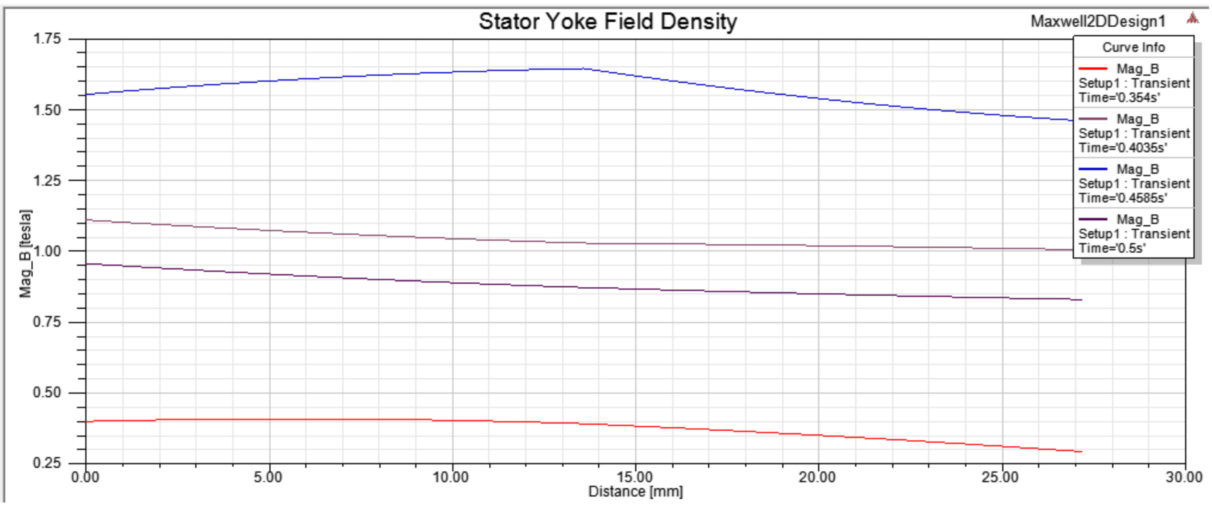


Figure 21-Stator Yoke Field Density

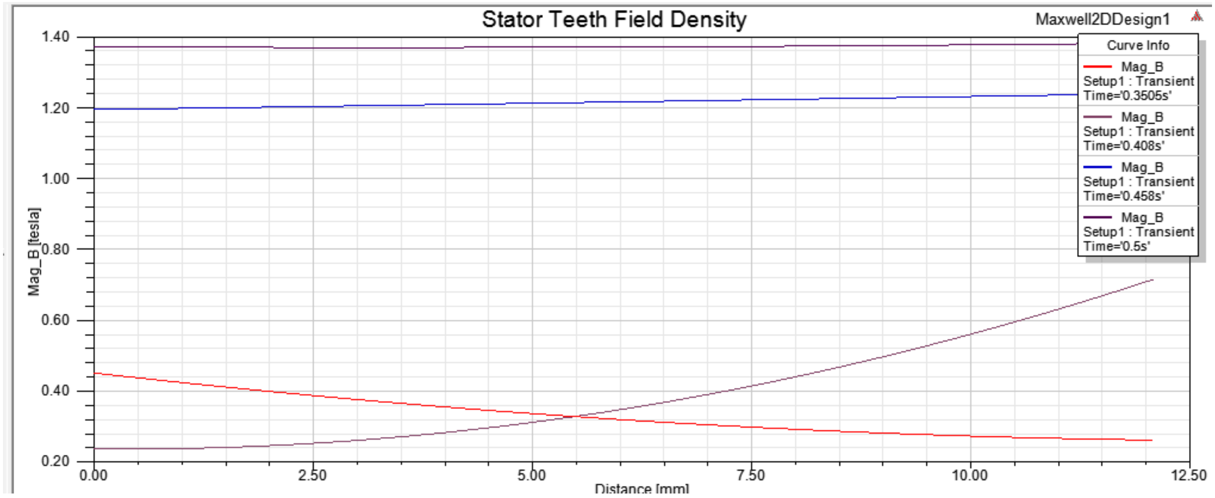


Figure 22-Stator Teeth Field Density

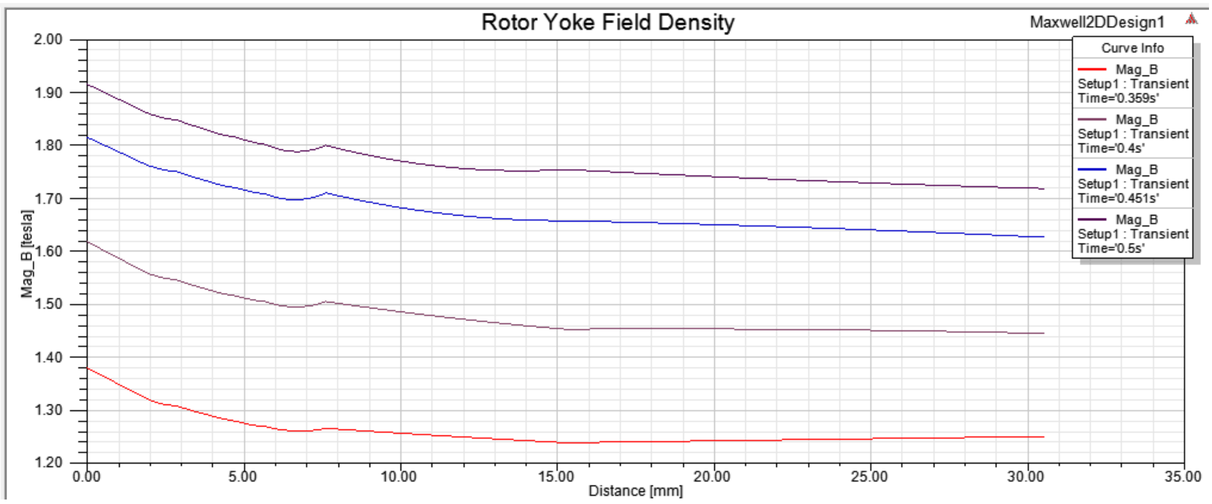


Figure 23-Rotor Yoke Field Density

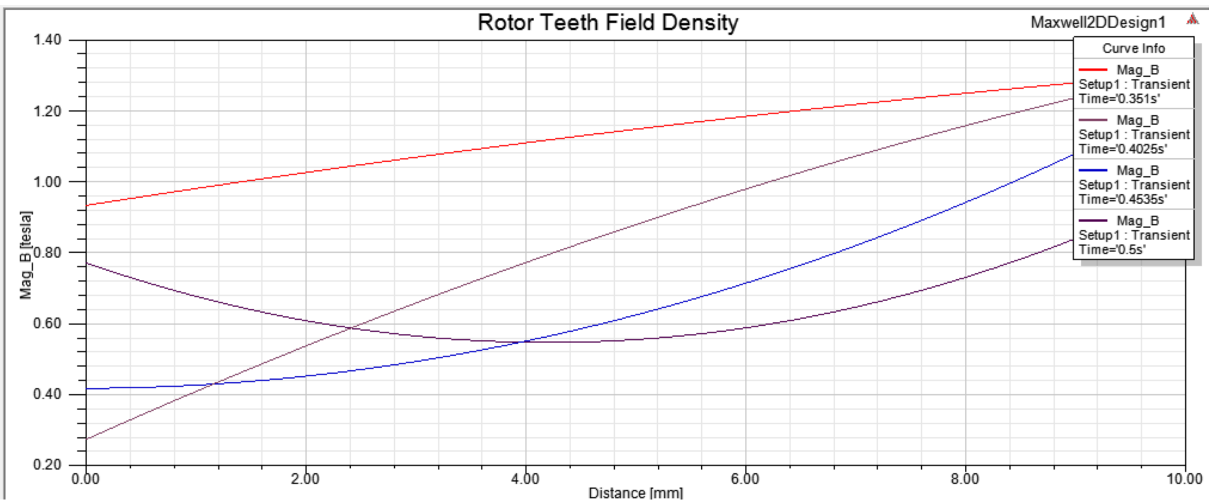


Figure 24-Rotor Teeth Field Density

- ✓ It can be seen that whole magnetic field densities at rotor yoke, tooth and stator yoke and tooth are like design ones and they don't exceed the design criteria shown below. If the designer cannot perform below criteria, it should check teeth width and yoke heights. If you decrease the rotor teeth, the magnetic flux density increases. This means that if you change the slot dimensions you obtain different torque-speed characteristics.

Table 6.2 Permitted flux densities of the magnetic circuit for various standard electrical machines

	Flux density B[T]			
	Asynchronous machines	Salient-pole synchronous machines	Nonsalient-pole synchronous machines	DC machines
Air gap	0.7–0.9 ($\hat{B}_{\delta 1}$)	0.85–1.05 ($\hat{B}_{\delta 1}$)	0.8–1.05 ($\hat{B}_{\delta 1}$)	0.6–1.1 (B_{max})
Stator yoke	1.4–1.7 (. . . 2)	1.0–1.5	1.1–1.5	1.1–1.5
Tooth (apparent maximum value)	1.4–2.1 (stator) 1.5–2.2 (rotor)	1.6–2.0	1.5–2.0	1.6–2.0 (compensating winding) 1.8–2.2 (armature winding)
Rotor yoke	1–1.6 (. . . 1.9)	1.0–1.5	1.3–1.6	1.0–1.5
Pole core	–	1.3–1.8	1.1–1.7	1.2–1.7
Commutating poles	–	–	–	1.3

Table 2-Flux densities of the motor

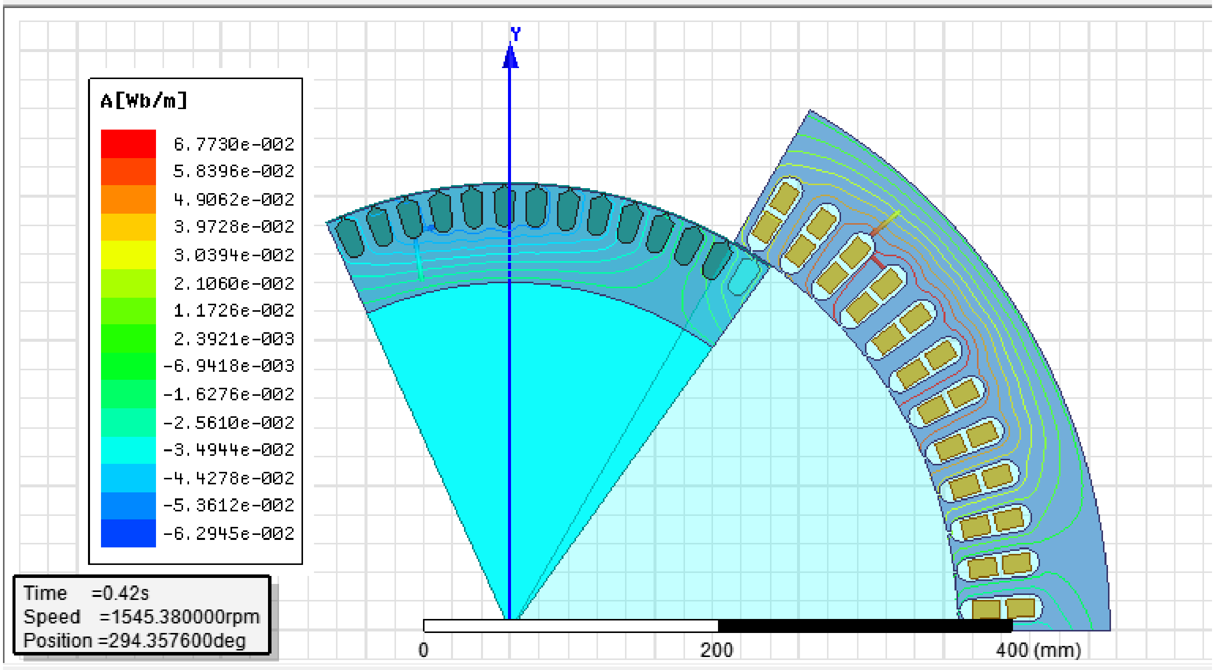


Figure 25- Flux Lines at second of 0.42

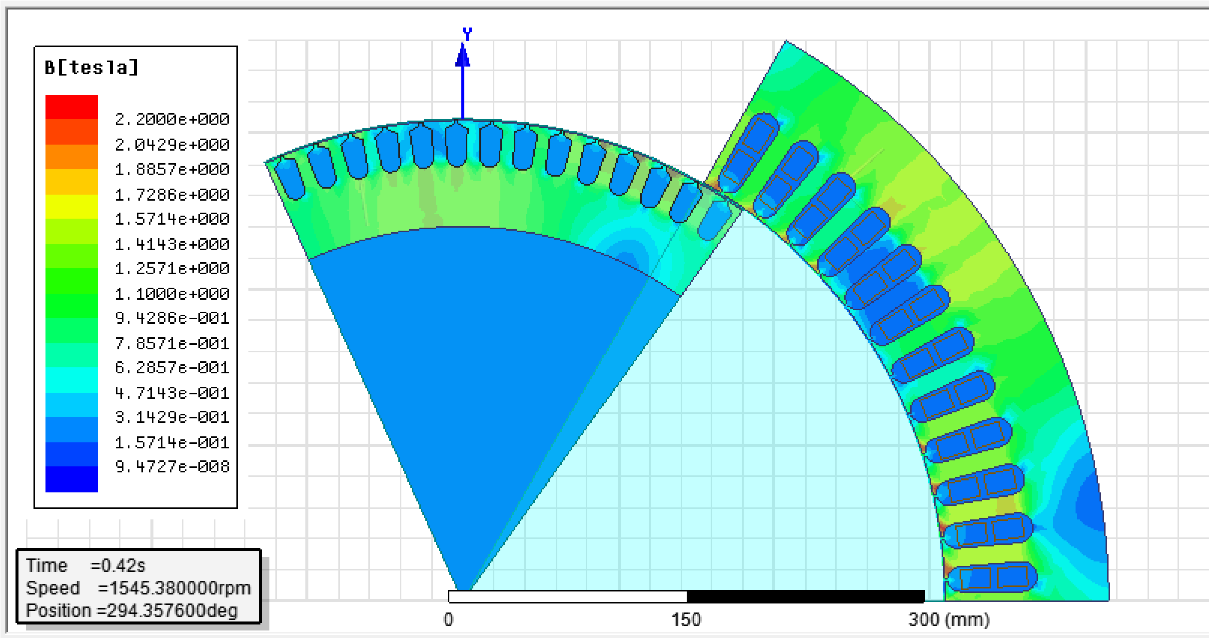


Figure 26- Magnetic field densities at second of 0.42

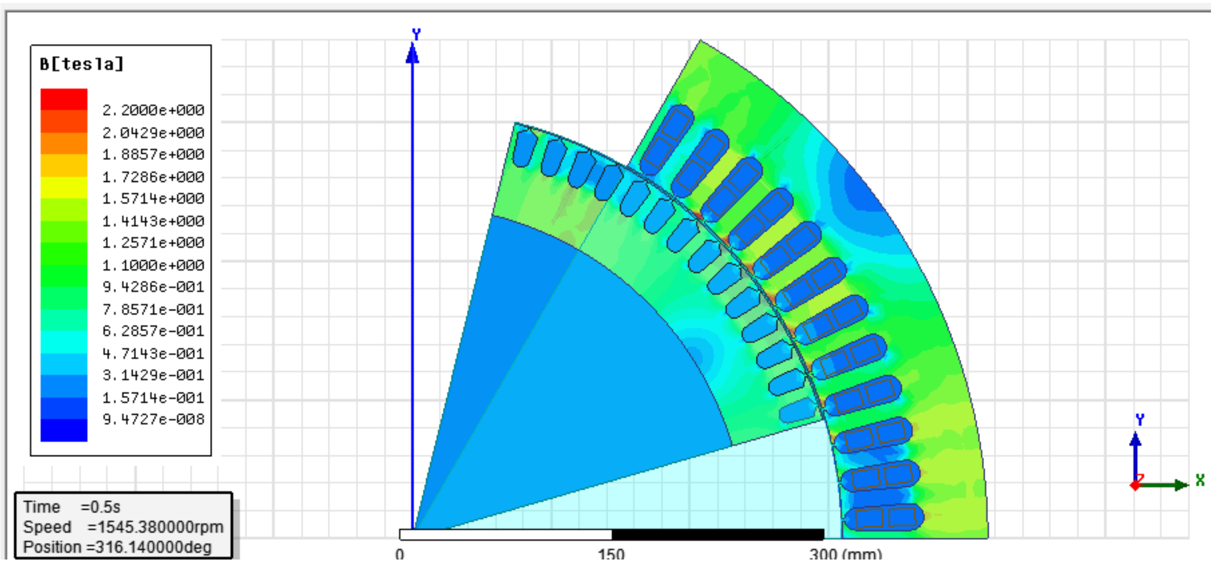


Figure 27- Magnetic field densities at second of 0.5

Lessons Learnt & Conclusion

In the beginning of Project-3, I started to fix my mistakes made at Project-2 design.

As general approach, the physical size of electrical machines is primarily determined by their torque capability, because the output torque is proportional to the product of the rotor volume and the shear stress. The shear stress in turn is proportional to the product of the electric and magnetic loading. Once the approximate rotor volume has been determined, other design decisions include the rotor aspect ratio, the stator slot diameter ratio and the number of poles. Therefore, the torque rating is the primary factor affecting motor sizing. Highly effective cooling methods increase the permitted electromagnetic loading and correspondingly the weight of the machine drops by 30–50 %.

- ➢ How to start to the design procedure;
- ✓ 1st - Define magnetic and electrical loading (electric field per unit)
- ✓ 2nd - Diameter (for power) and axial length
- ✓ 3rd - Define the airgap (smaller the better)- (0.0001mm is the perfect!)
- ✓ 4th - Winding type and number of coils
    - Slots,tooths
    - Calculation of machine performance
    - Lots of iteration and optimization

With a constant supply frequency, the rotor peripheral speed in rotating-field machines is proportional to the pole pitch.

The permitted armature current and thereby the machine constant are functions of the pole pitch and the frequency of the machine

At the design stage, firstly Cmech parameter is determined. This parameter is defined in the literature as machine constant, Cmech. Cmech is a machine constant of totally enclosed asynchronous and synchronous machines as a function of pole power. Magnetic and electrical loading cannot be used as a determination because of unknown parameters slot pitch, diameter and length of the machines at start. After that, the motor dimensions are determined thanks to the formula of aspect ratio. Then, air gap diameter is deduced.

The torque is produced at the air gap. Smaller the air gap length, the better for operation. However, if the application requires high torque, increasing of air gap diameter will be better.

In numerical methods, Maxwell's stress tensor is often employed in the calculation of forces and torque. The stress occurs in the direction of lines of force and creates an equal pressure perpendicularly to the lines. Considering torque production, the tangential component is of the greatest interest. The total torque exerted on the rotor can be obtained by integrating the stress tensor for instance over a cylinder that confines the rotor. Tangential stress expression is a very important starting point for the dimensioning of an electrical machine. Therefore, at the next stage tangential stress of the motor is calculated. It is checked from the lookup table. The next step is to determine the air gap length. In machines in which the magnetizing current is taken from the supply network, the length of the air gap is dimensioned to produce a minimum magnetizing current and, on the other hand, an optimal efficiency. A small air gap gives a low magnetizing current. A small air gap also increases the surface losses in the rotor caused by the current linkage harmonics of the stator. There is no theoretical optimum solution to define air gap length, but empirical solutions may be employed. Generally, in frequency converter drives, the air gap may be increased similarly as in heavy-duty drives (60% increase) to get lower rotor surface losses. After determining the air gap lengt, stator dimensions are exerted and then the number of slots and slot pitches for stator. The more slots in the stator, the more sinusoidal current linkage produced by the winding approaches sinusoidal waveform. The more slots, the more number of coils and also the more expensive of the machine. A guiding principle is that a poly-phase winding produces the more sinusoidal current linkage, the more slots there are in the stator. A large number of slots increase the number of coils and also the price of the machine. If possible use as, it is often advisable to connect the coils in series, since in that case the possible asymmetries between the pole pairs do not cause circulating currents in the machine.

As the winding configuration is chosen, it is determined as a double-layer winding. The chording factor (pitch factor) is 5/6 is chosen to reduce 5th and 7th harmonics at stator windings. Whenever the coil span is reduced below full pole-pitch, the phasor sum of the conductor voltages in the slots becomes less than their arithmetic sum. This reduction is expressed in the pitch factor formula. After that number of turns/phase are determined. Air gap flux density is determined by using lookup table that contains permitted flux densities of the magnetic circuit for various standard electrical machines. After determining the air gap flux density, the linear current density is checked. As the main dimensions, the winding method and the air-gap density have been selected, and the required number of winding turns N is defined with a desired emf. After determining, number of turns the rotor slot number and rotor slot pitch is calculated. It depends on the slots per pole and phase qs of the stator and the number of pole pairs, when the rotor bars are skewed for the amount of one stator slot pitch.

Also, the skewing is preferred here for preventing the cogging phenomenon. It is a phenomenon in which, if the rotor conductors are straight, there are chances of magnetic locking or strong coupling between rotor & stator. The second reason for skewing is to avoid crawling is a phenomenon where harmonic components introduces oscillations in torque. Skewing the rotor has advantage is that due to increase in length of Rotor conductors as their resistance increases leading to slightly higher starting torque.

At the design, aliminium rotor is used to increase the starting torque. Higher the rotor resistance means higher starting torque but lower efficiency by comparing to its counterpart of copper rotor. After that rotor and stator slot dimensions are determined. If you decrease the rotor teeth, the magnetic flux density increases. This means that if you change the slot dimensions you obtain different torque-speed characteristics. Then the magnetic flux densities at stator yoke and in the simulation stator teeth,rotor yoke, rotor teeth and air gap flux density is shown at the report.

General Tips

- ✓ The dimension of motor doesn't change with the power but changes with its torque capacity.
- ✓ For high torque required applications, increasing of air gap diameter is logical for better solution.
- ✓ For heavy duty motors, the designer should increase the airg ap by 60%. For converter driven motors, motors airgap can be increase by 60% to reduce the rotor surface losses.
- ✓ If you increase the pole number of the machine, you get smaller your design. Flux created by the stator also passes through the rotor and turns back to stator. It is because if you increase the pole number,you get smaller the return path for flux linkage and therefore the diameter is reduced.
- ✓ To increase starting torque for induction machine, use aliminium instead of copper even if copper one is more efficient.
- ✓ Endring width and height becomes extremely high the torque ripple will increase.
- ✓ Always check the flux densities at teeth and yokes.
- ✓ Use skewing to reduce oscillates at the torque and obtain higher starting torque.
- ✓ Use chording at winding to reduce the harmonics
- ✓ Reduce hysteresis and eddy current losses. Using thinner laminations to reduce eddy current losses.
- ✓ Designing of a motor needs so much iterations

END OF THE REPORT