EPSRC
Pioneering research and skills

Theme 4 – Motors

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Manchester University
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PM Machine Design and Analysis

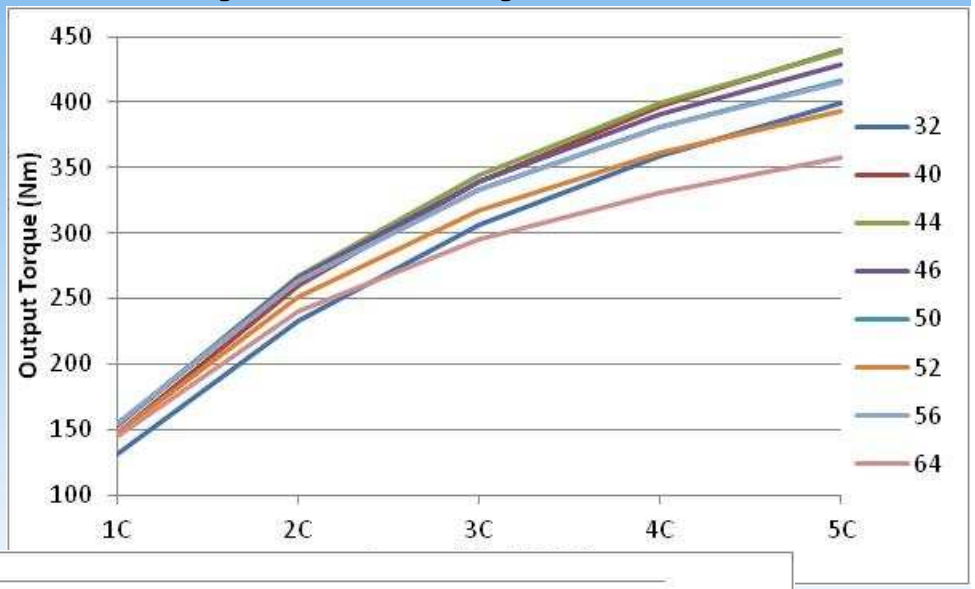
- In-wheel direct drive PM machine
  - Overload investigation
  - Modular design of stator
  - Mechanical design
- Interior Ferrite PM machine
  - Stator slot number investigation
  - Rotor surface profiling

Direct-Drive Rare Earth PMSM

Overload capability analysis

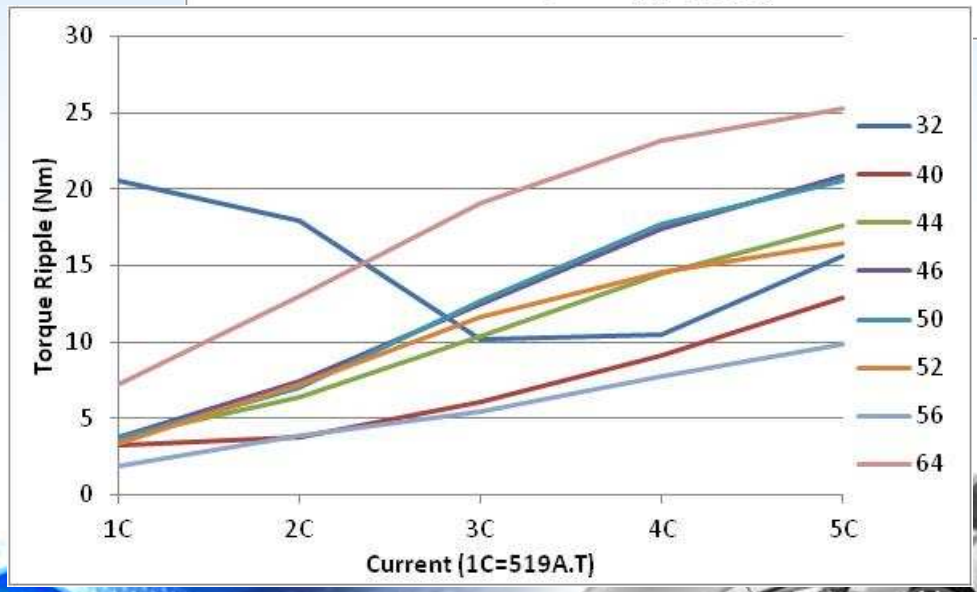
Torque (Nm)

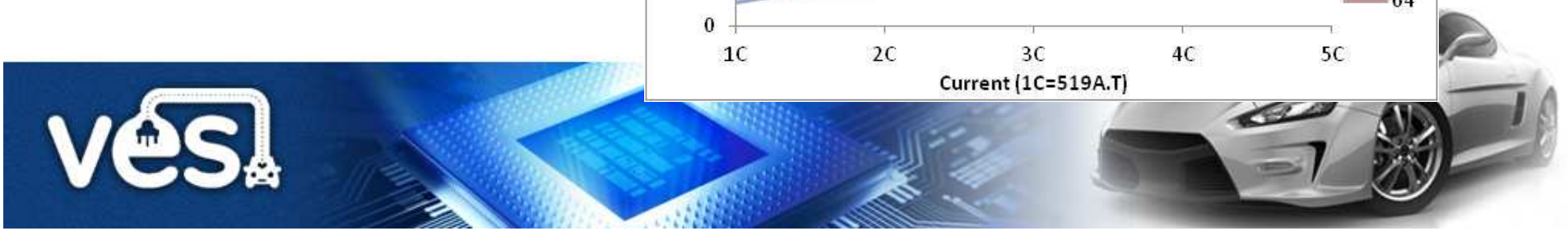
Poles	1C	2C	3C	4C	5C
32	131.6311	232.7221	305.691	359.0276	399.8291
40	147.1169	259.9389	339.1598	396.7963	439.7842
44	152.9039	266.9588	344.5163	398.6462	438.4259
46	153.4276	265.5477	339.788	390.8155	428.2787
50	154.089	263.2532	333.4273	381.0759	415.997
52	146.9392	250.8565	316.8907	361.2332	393.4844
56	154.8293	263.7777	333.2905	380.3729	414.5392
64	144.2186	239.9428	295.1202	330.8753	357.1229



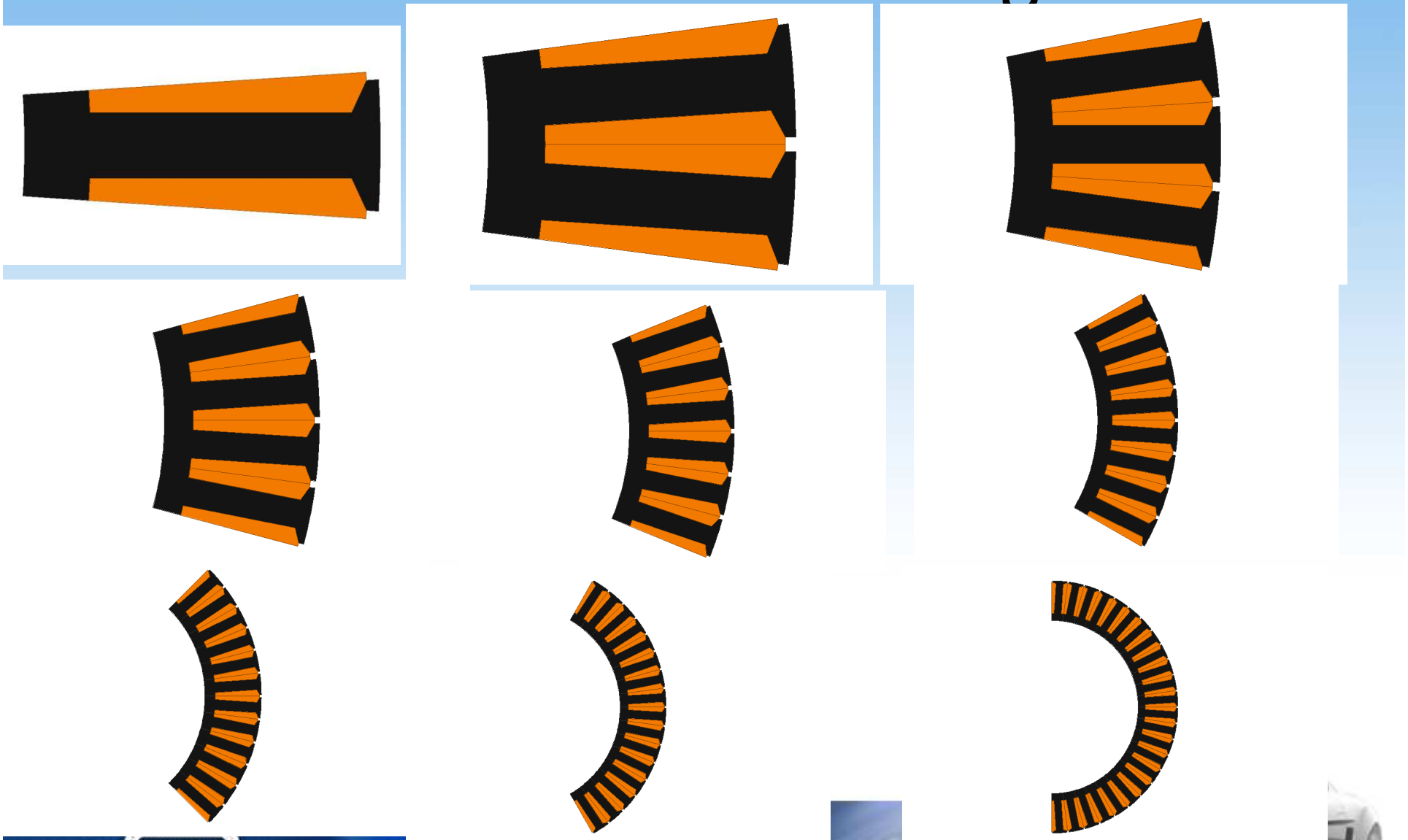
Torque Ripple (Nm)=(Max(Torque)-Min(Torque))/2

Poles	1C	2C	3C	4C	5C
32	20.6046	17.9751	10.1490	10.5178	15.6198
40	3.2137	3.7581	6.0879	9.1576	12.9566
44	3.7337	6.4570	10.3853	14.4864	17.5988
46	3.8264	7.4024	12.4788	17.4061	20.8626
50	3.7246	6.9857	12.6449	17.7183	20.5978
52	3.3505	7.1927	11.6791	14.6145	16.4292
56	1.9286	3.9104	5.5070	7.7199	9.8650
64	7.2710	12.9927	19.1058	23.2057	25.2601

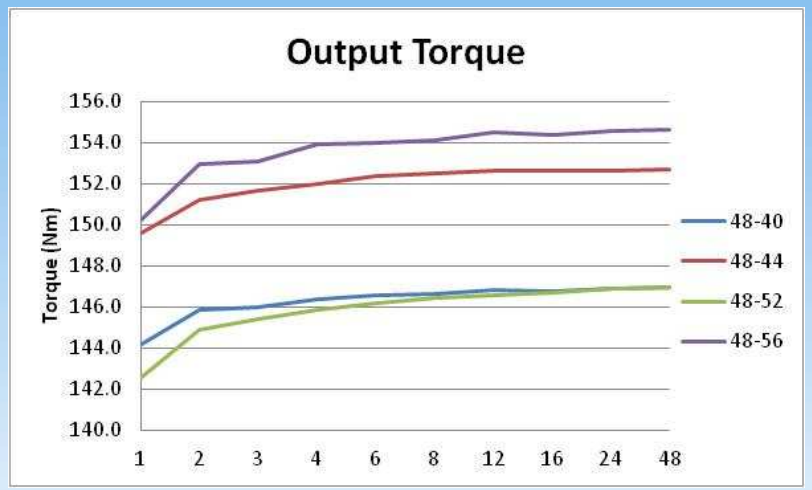


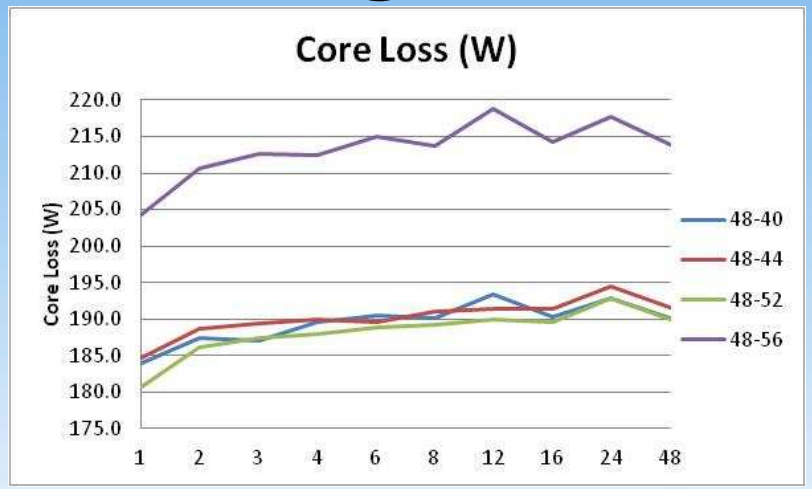


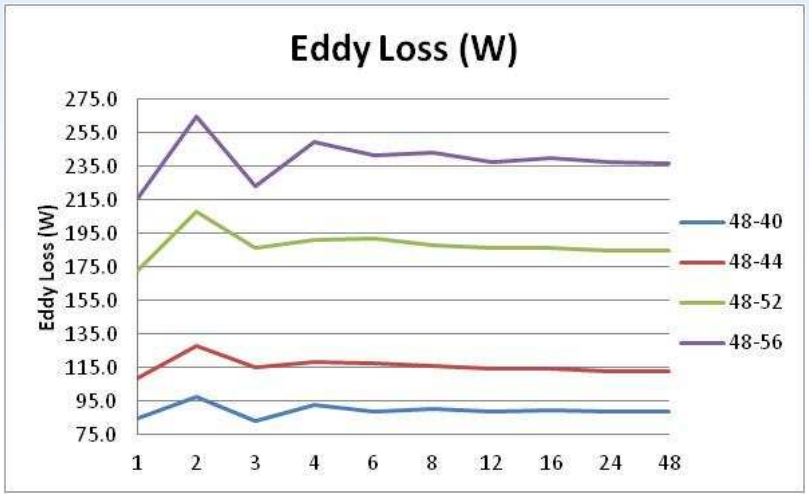
Stator Modular Design

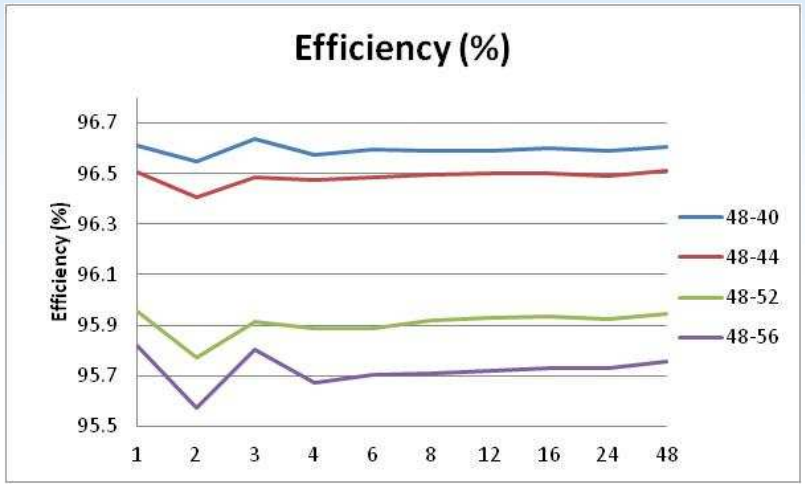


Stator Modular Design



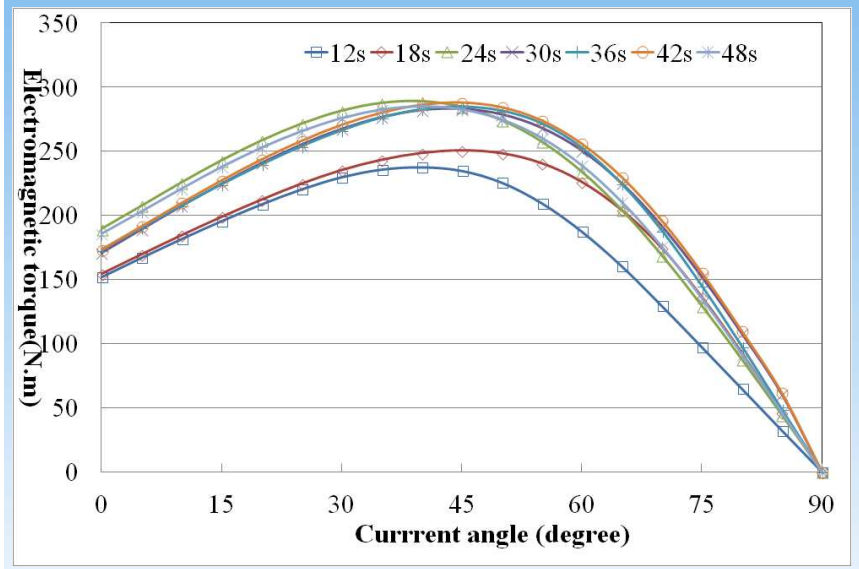


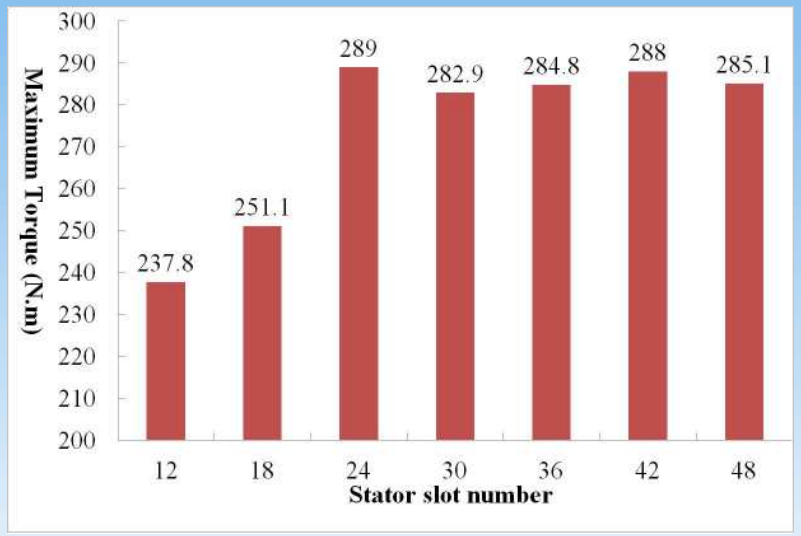


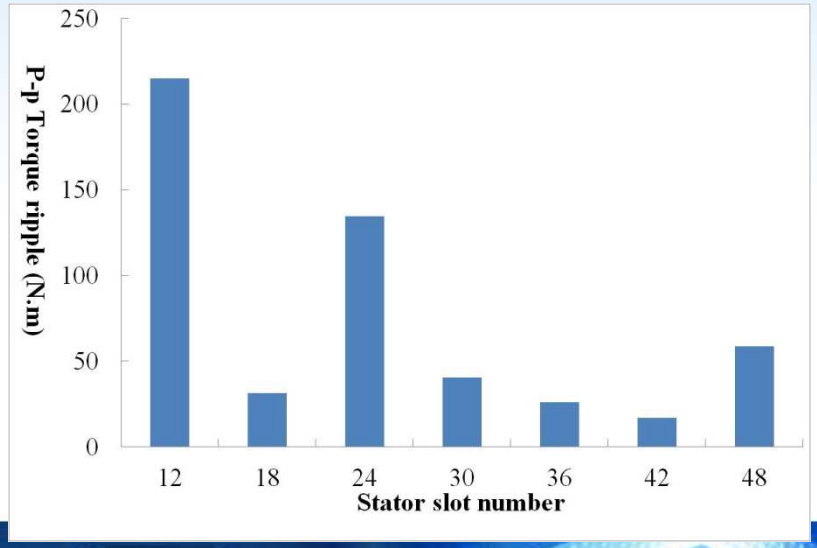


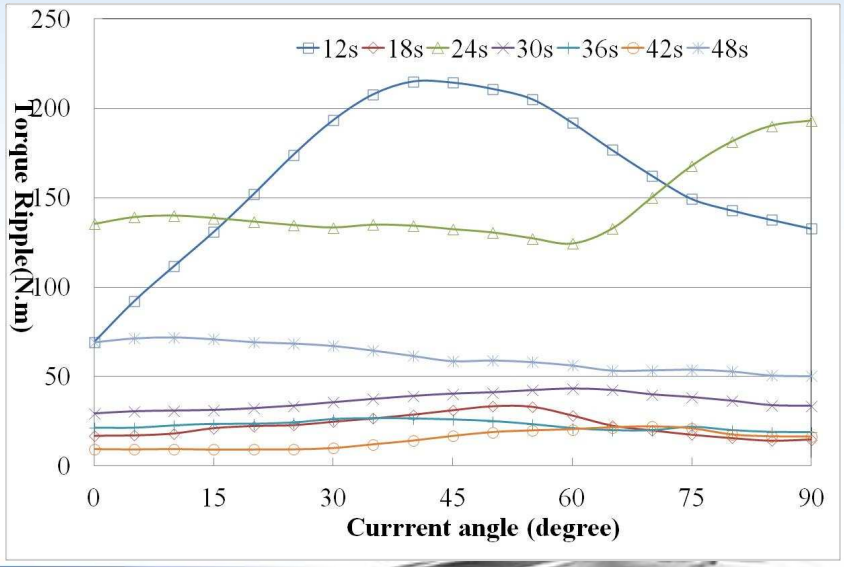
Interior Ferrite PMSM

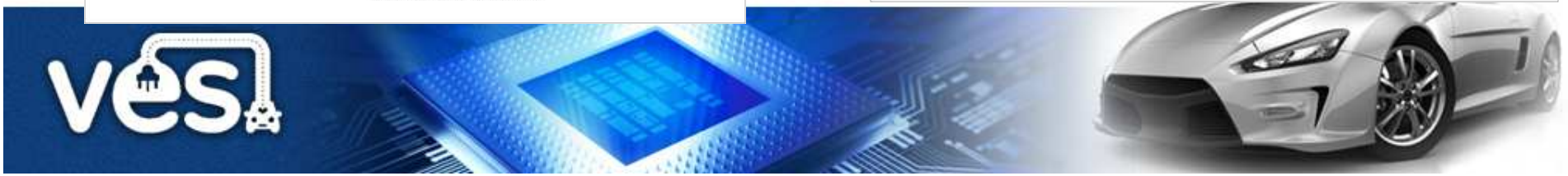
Optimal machines with different stator slots





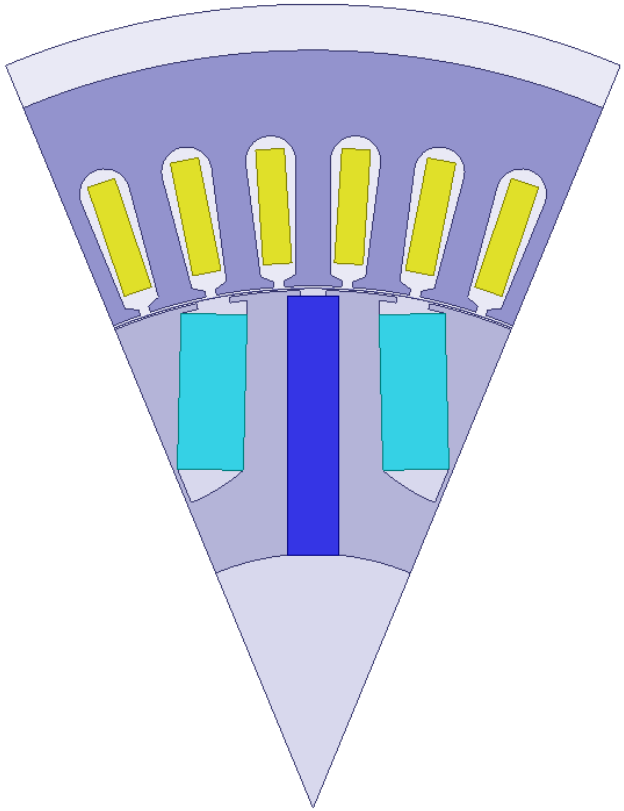


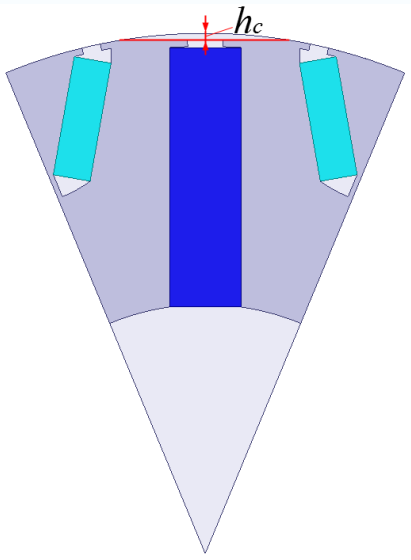


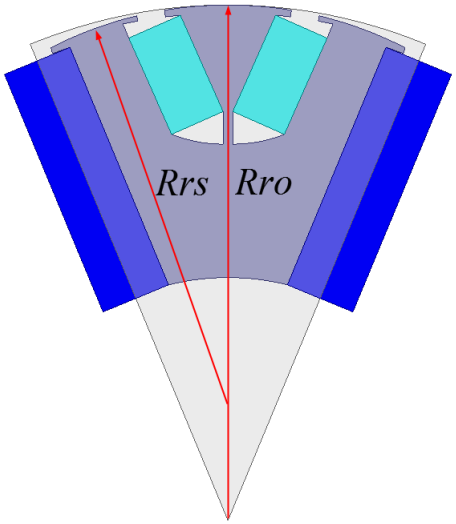


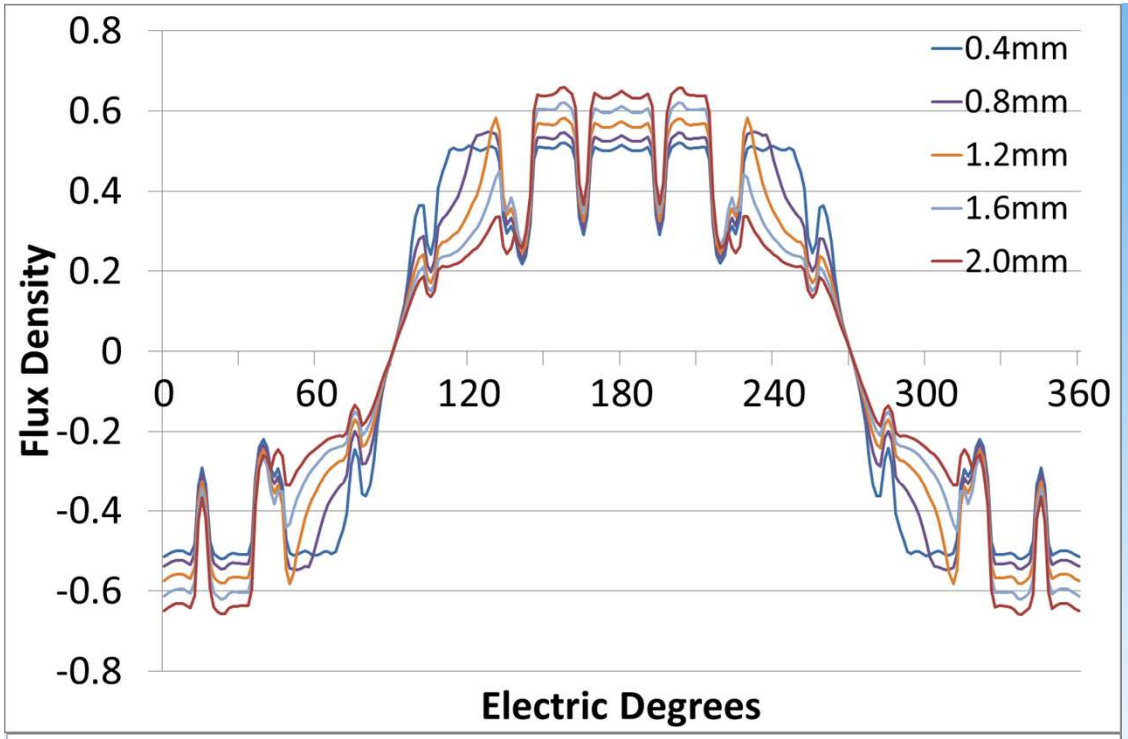
In order to improve the flux density in the airgap, 2 type of uneven airgap rotor is analysed:

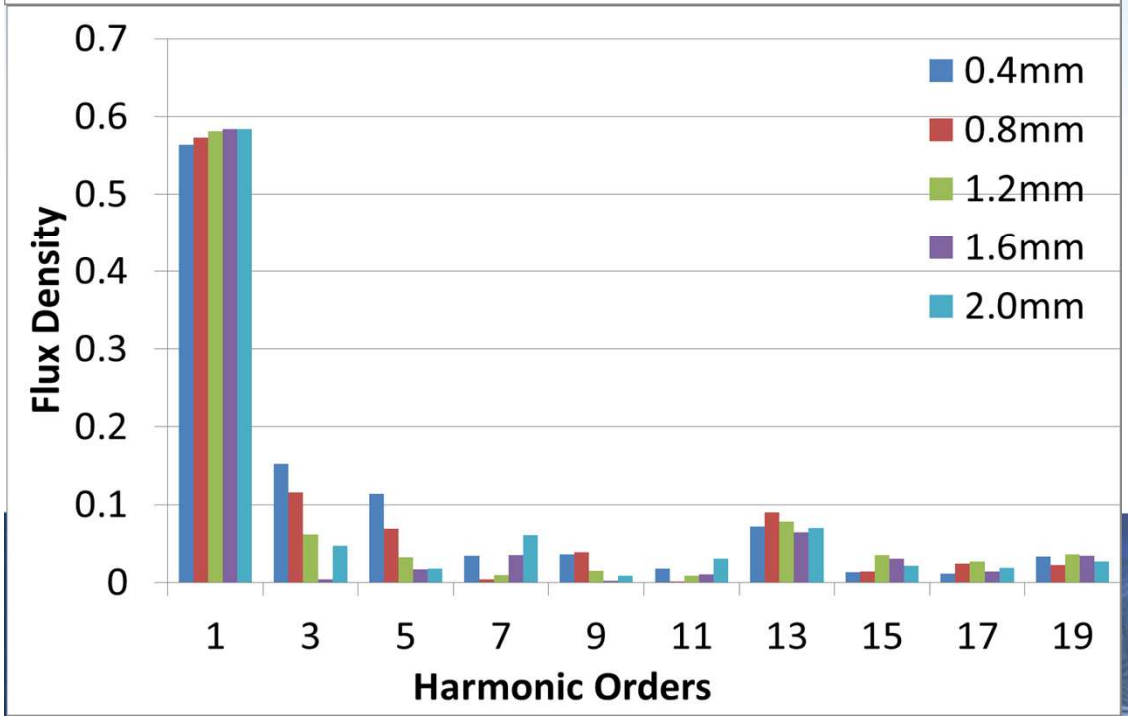
- Flat type
- Circular type

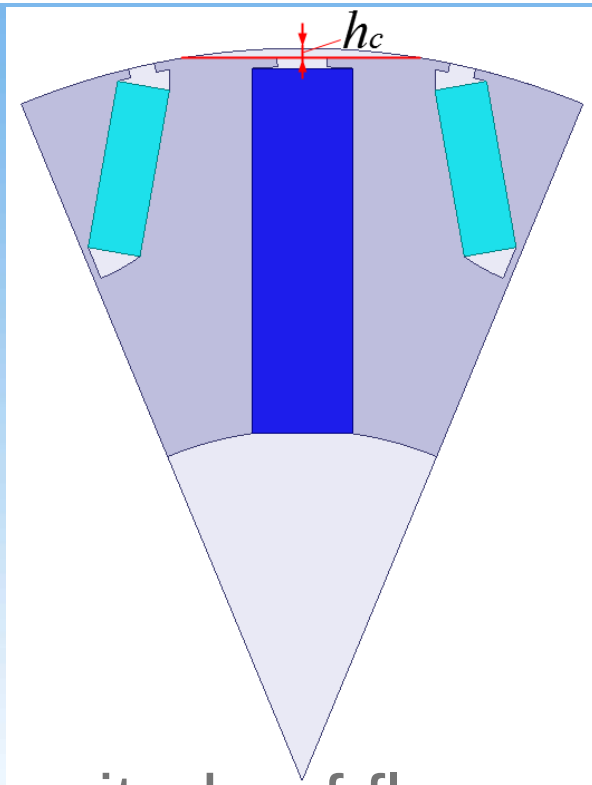




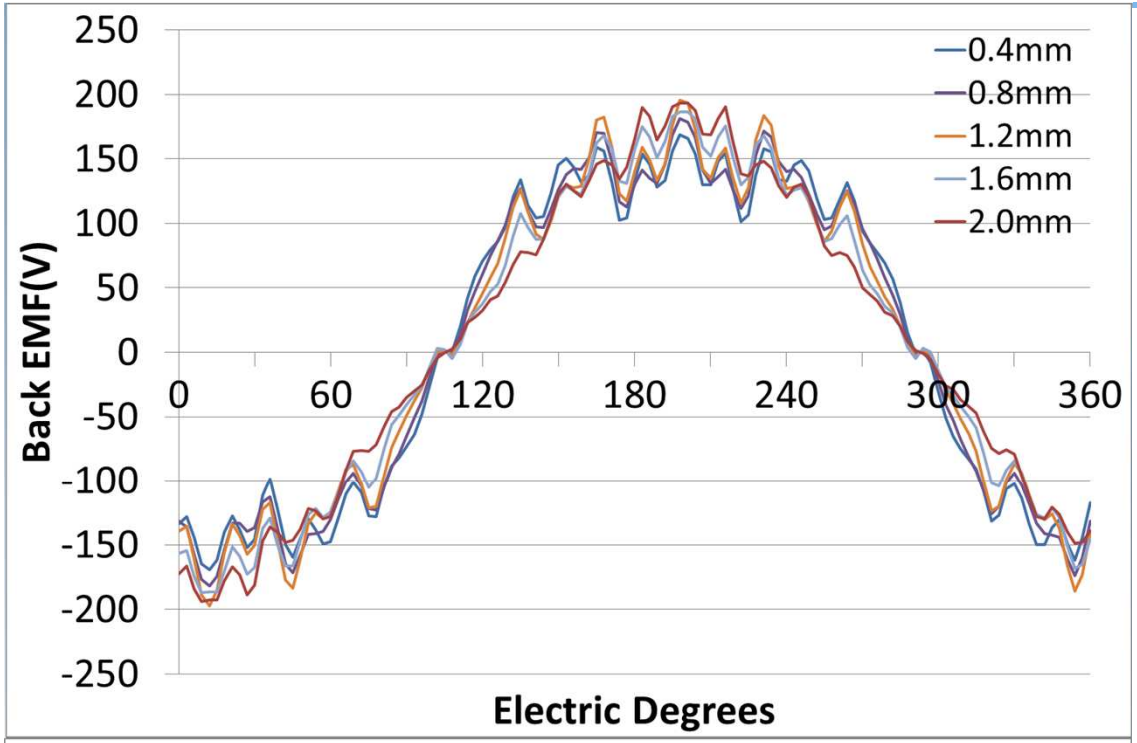


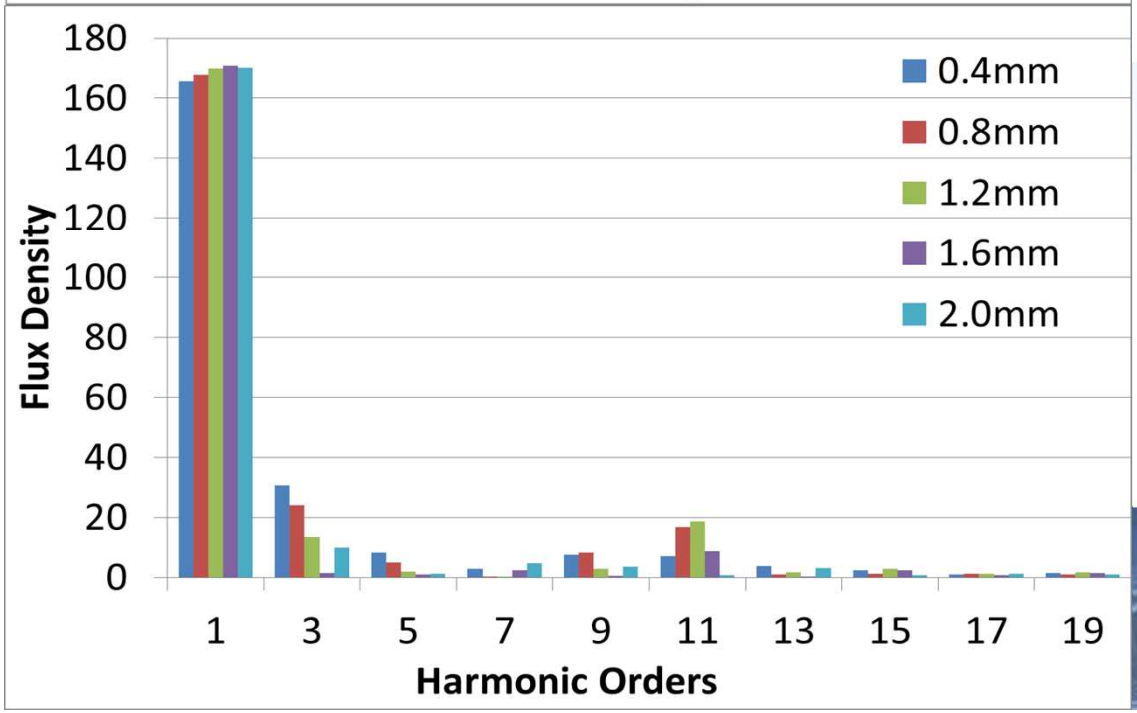


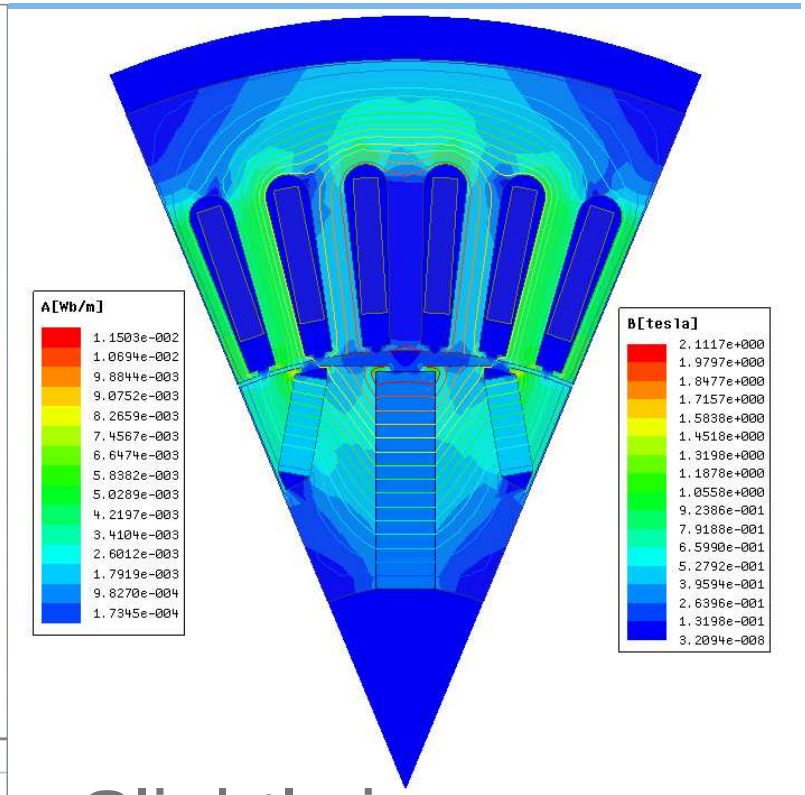




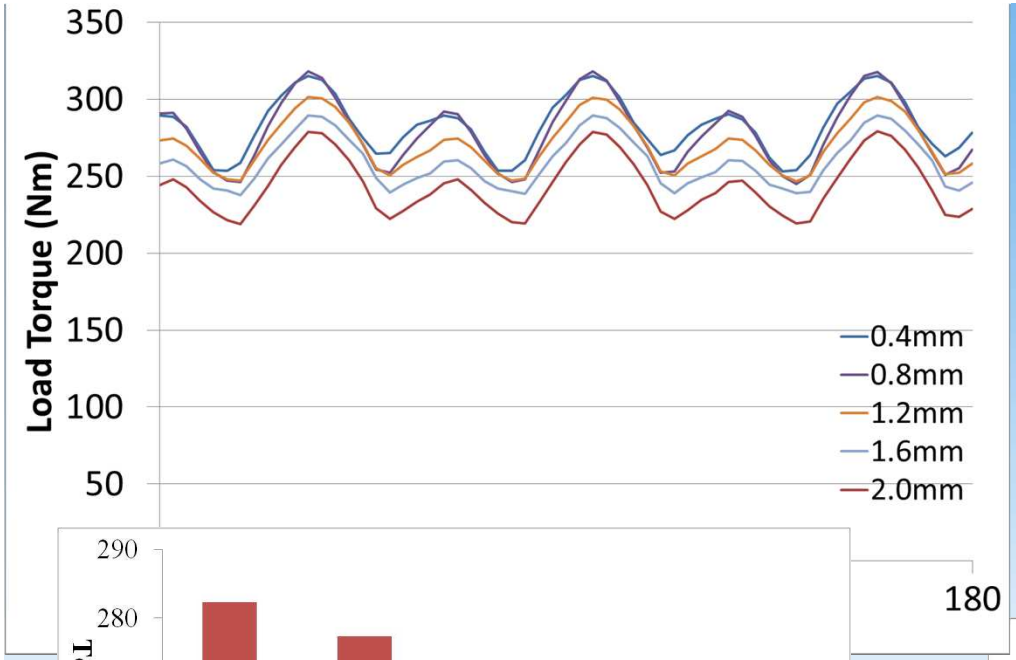
- Magnitude of flux density is increase.
- 3 and 5 order harmonics can be reduced.

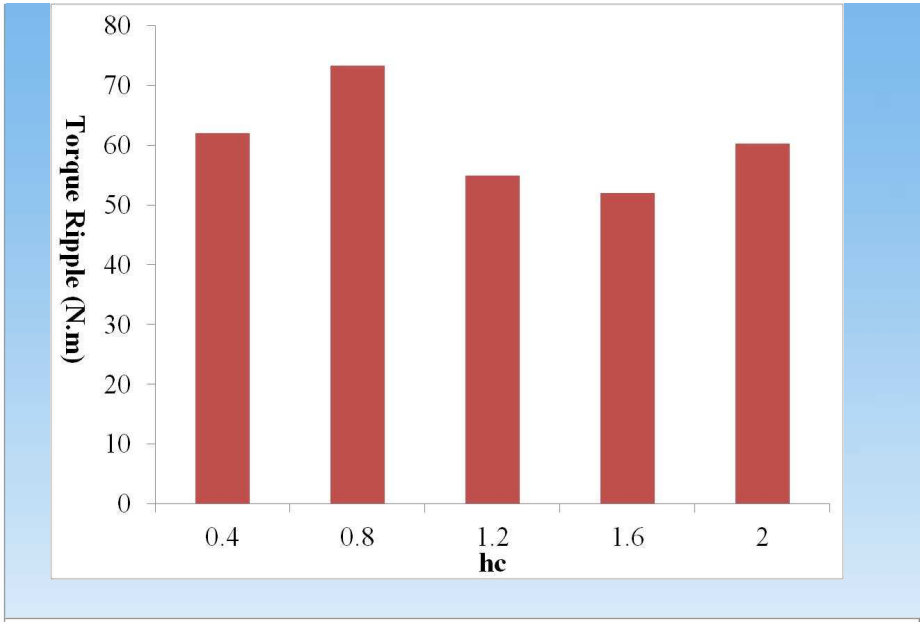


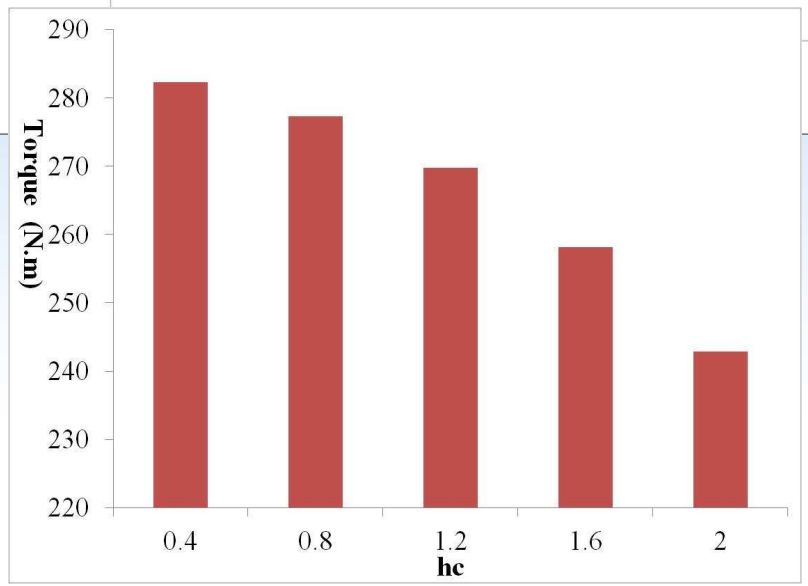


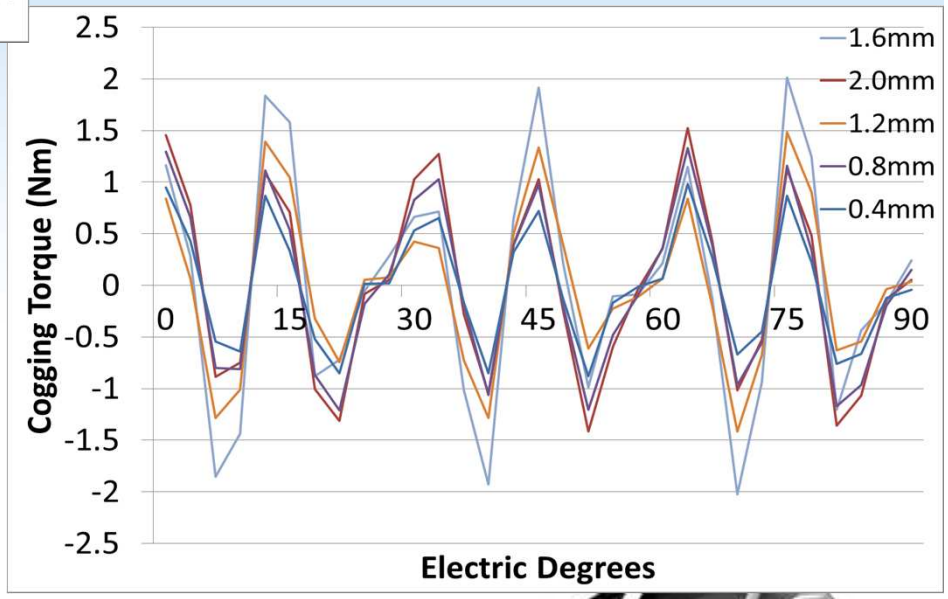


- Slightly increase Fundamental component with a maximum at 1.6mm.

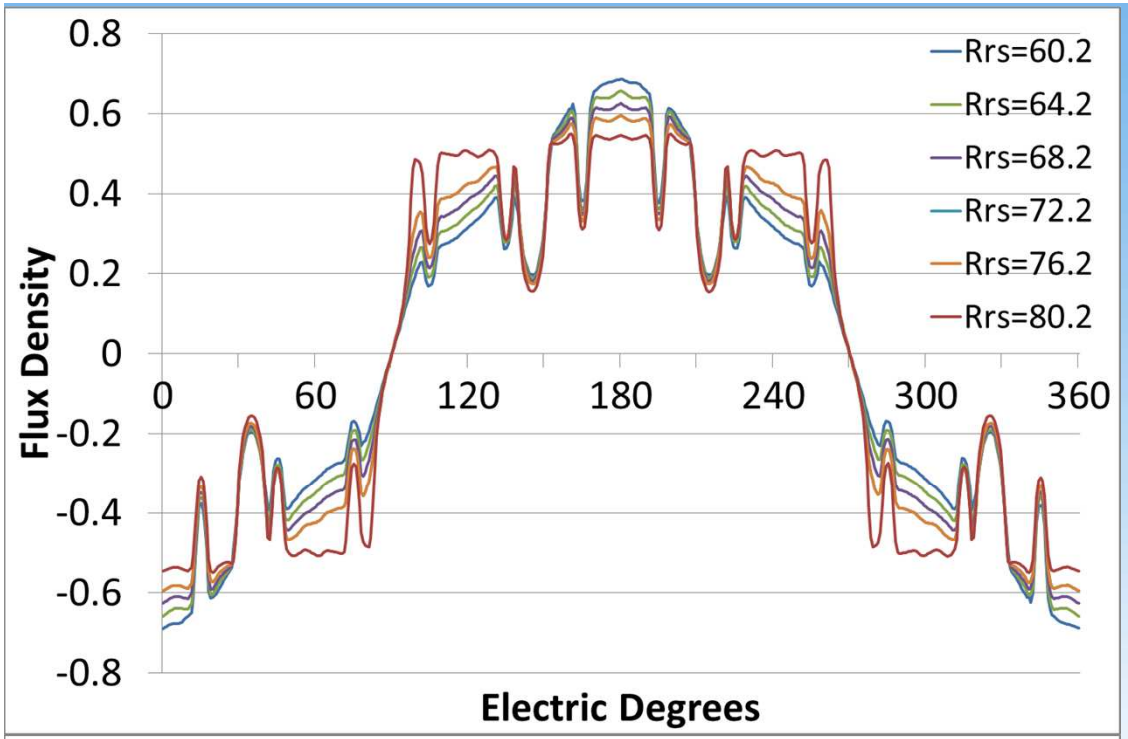


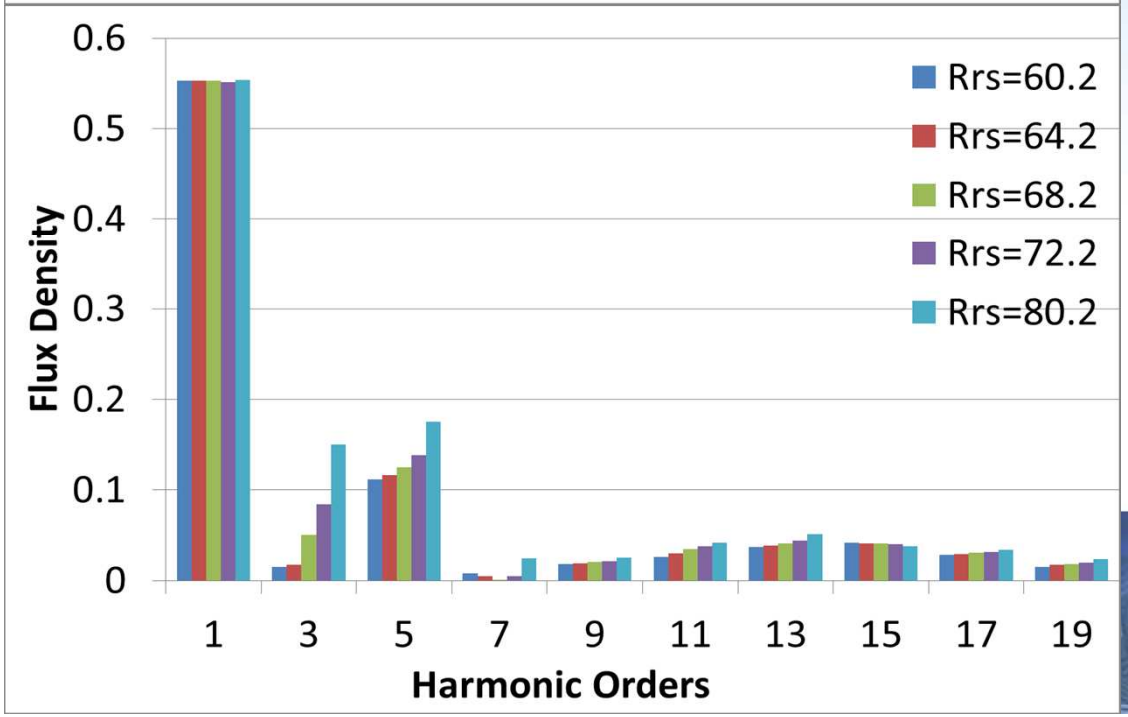


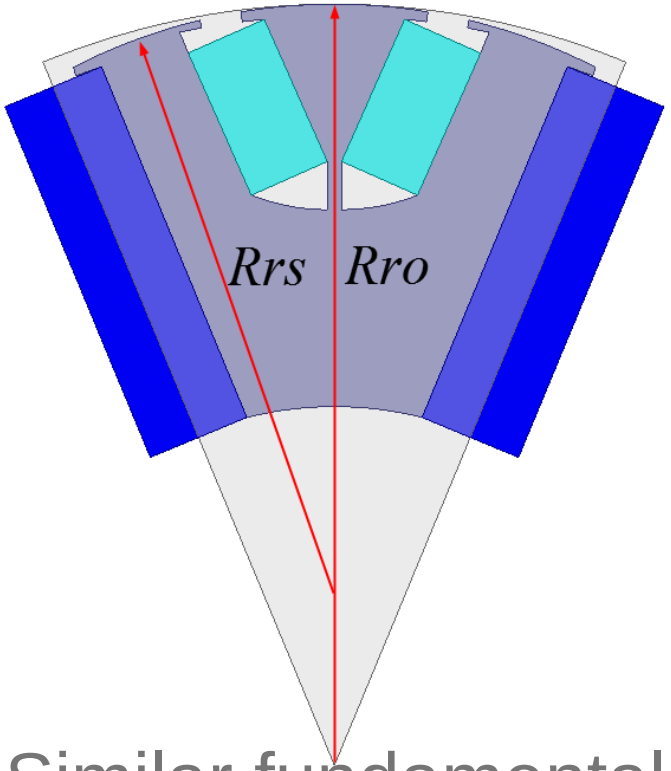




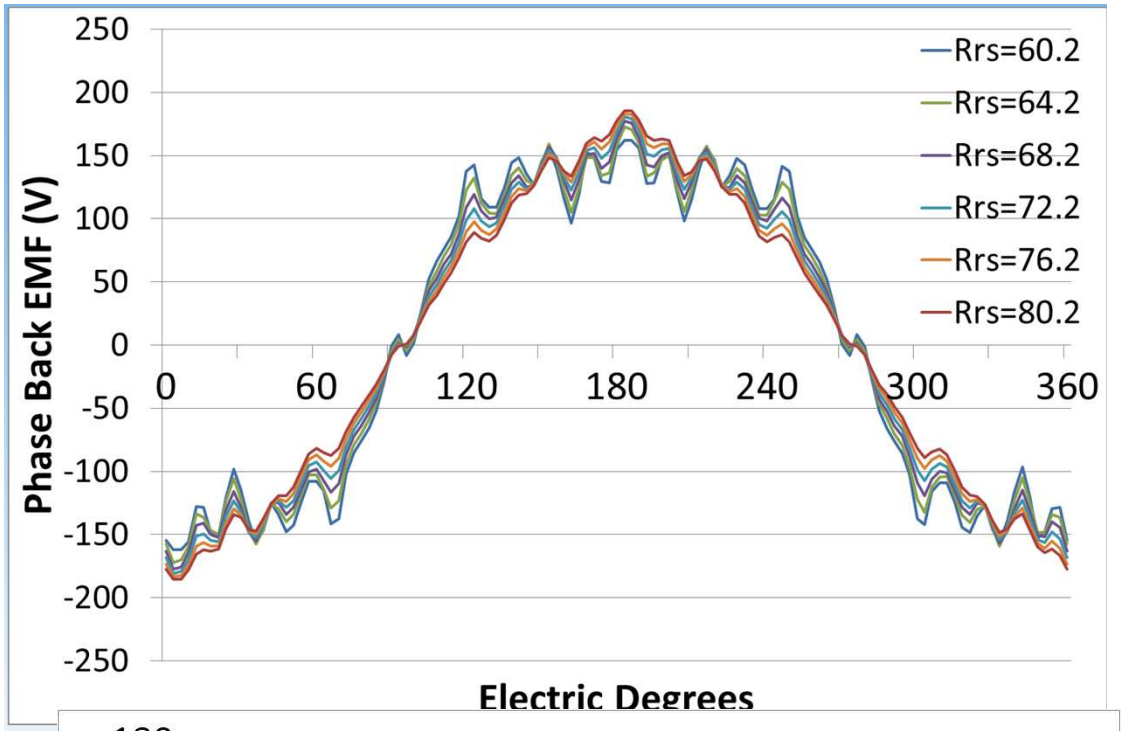
- Load torque will be reduced.
- cogging torque will be increased.

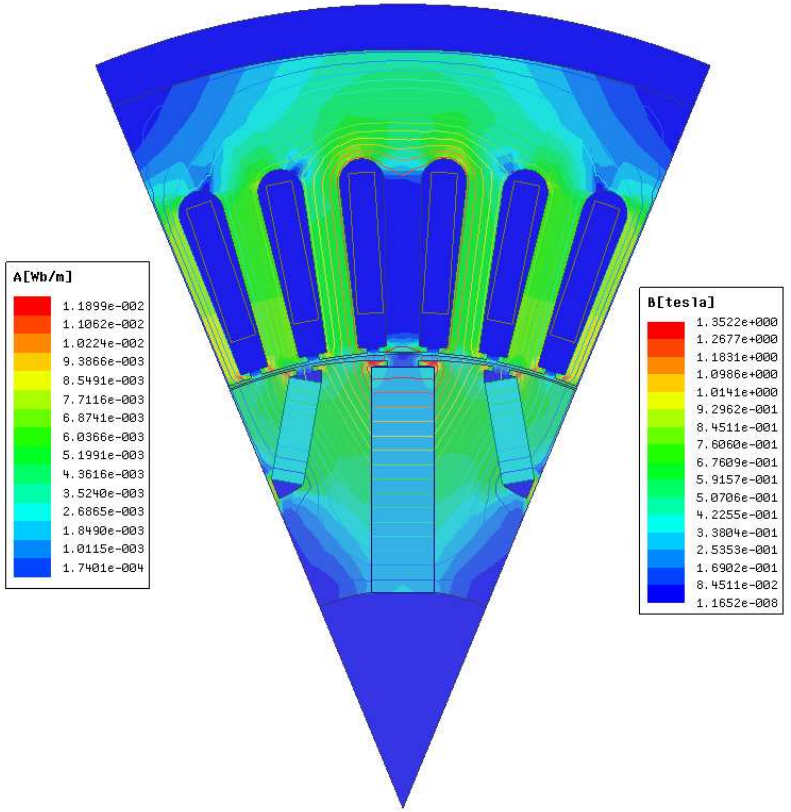


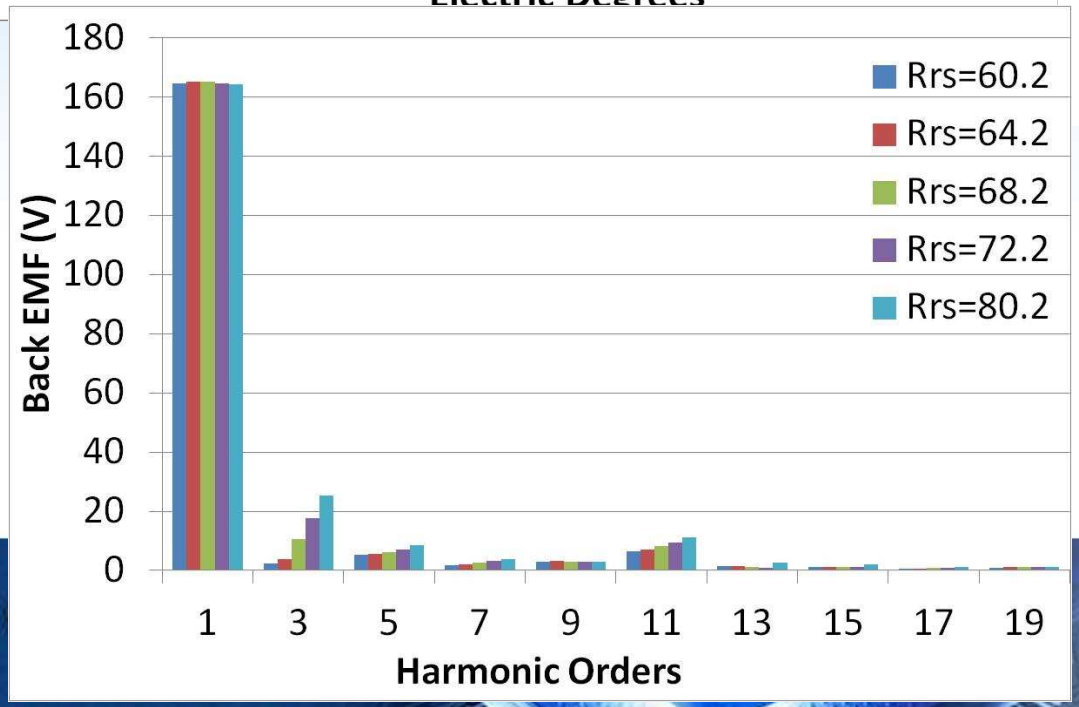


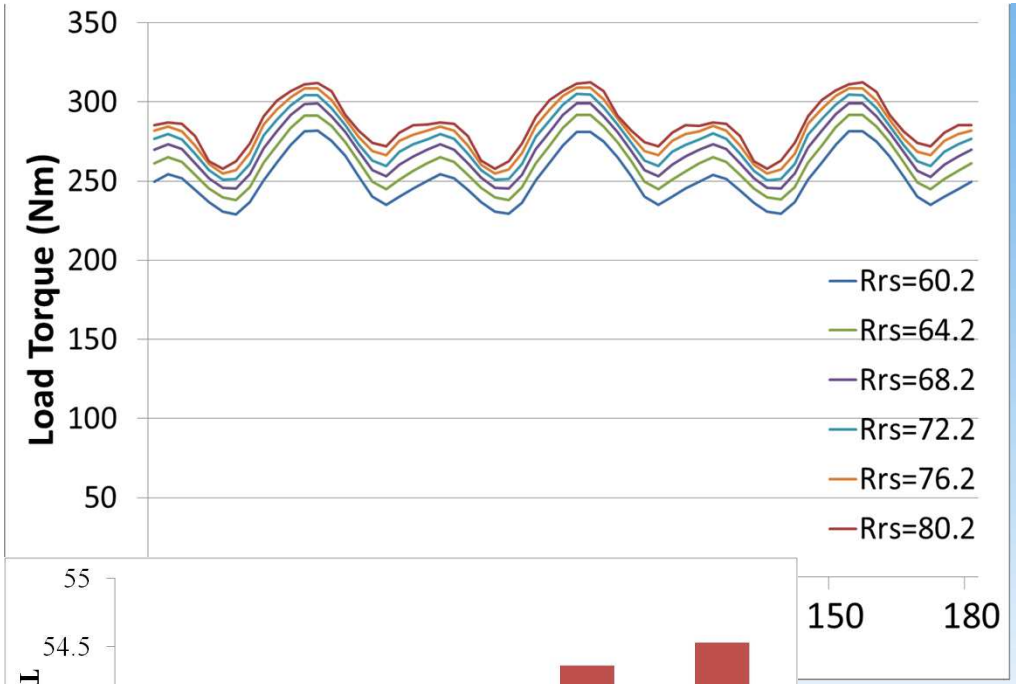


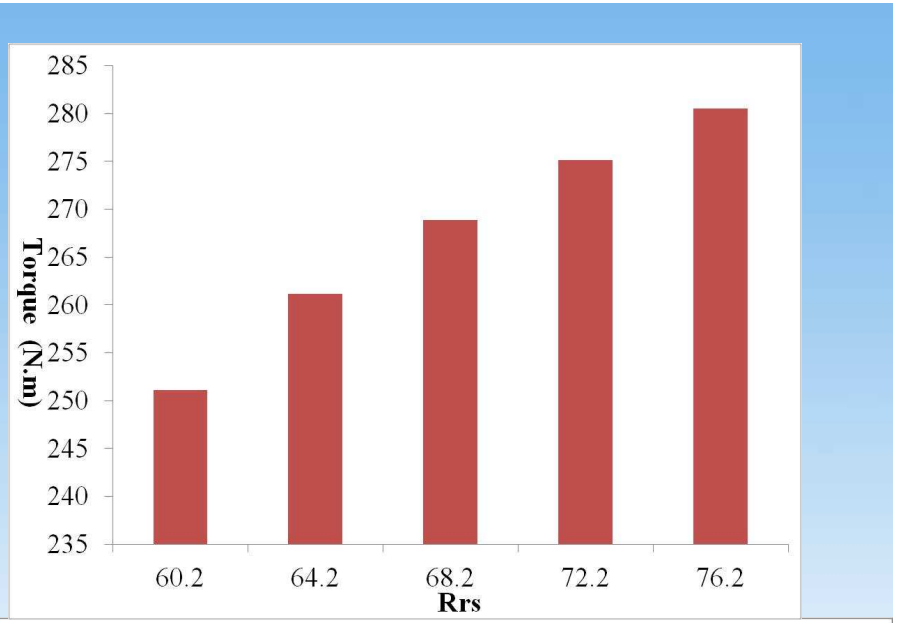
- Similar fundamental component.
- Reduced 3rd order harmonic component.

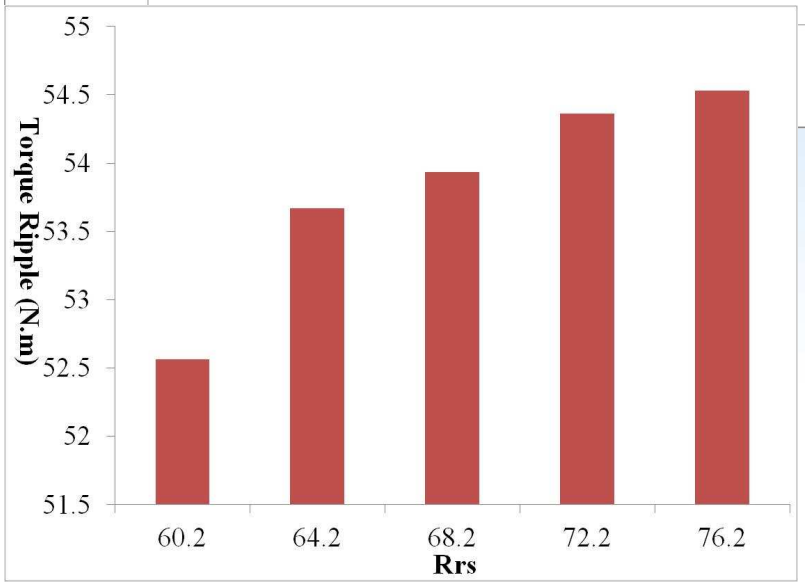

Phase Back EMF (V)
250
200
150
100
50
0
-50
-100
-150
-200
-250
0
60
120
180
240
300
360
Electric Degrees
Rrs=60.2
Rrs=64.2
Rrs=68.2
Rrs=72.2
Rrs=76.2
Rrs=80.2

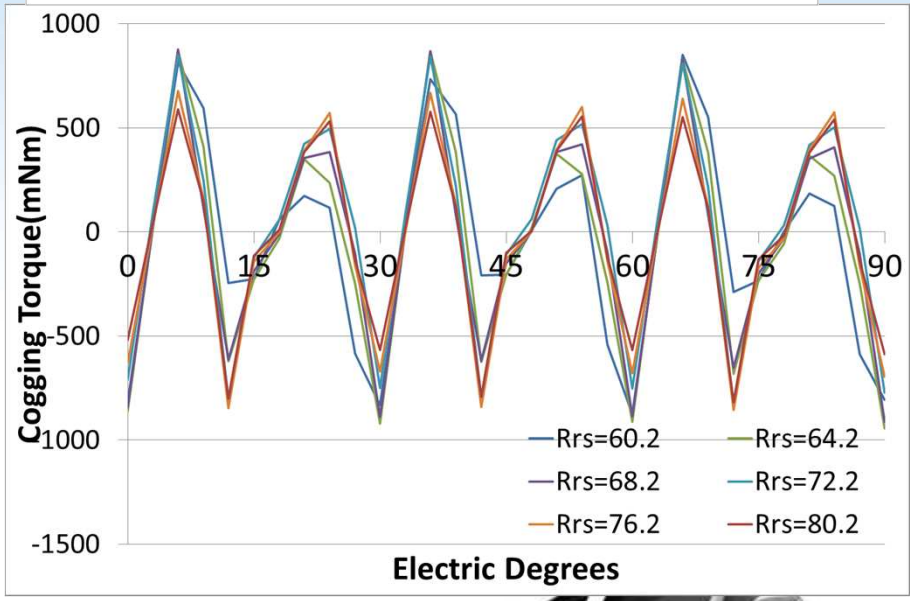

A[Wb/m]
1.1899e-002
1.1062e-002
1.0224e-002
9.3866e-003
8.5491e-003
7.7116e-003
6.8741e-003
6.0366e-003
5.1991e-003
4.3616e-003
3.5240e-003
2.6865e-003
1.8490e-003
1.0115e-003
1.7401e-004
B[tesla]
1.3522e+000
1.2677e+000
1.1831e+000
1.0986e+000
1.0141e+000
9.2962e-001
8.4511e-001
7.6060e-001
6.7609e-001
5.9157e-001
5.0706e-001
4.2255e-001
3.3804e-001
2.5353e-001
1.6902e-001
8.4511e-002
1.1652e-008


Back EMF (V)
180
160
140
120
100
80
60
40
20
0
1
3
5
7
9
11
13
15
17
19
Harmonic Orders
Rrs=60.2
Rrs=64.2
Rrs=68.2
Rrs=72.2
Rrs=80.2









- Load torque will be reduced.
- Cogging torque is similar and much smaller than Type I rotor.

Further work

- In-wheel direct drive PM machine
  - Flux weakening capability analysis and improvement
  - Mechanical drawing and manufacture
  - Drive development and testing
- Interior Ferrite PM machine
  - Further optimization with control algorithm
  - Rotor integrity analysis and design
  - Mechanical design