Ironless Double Rotor Radial Flux Air-cored PM Machine

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Outline

The IDRFAPM Machine

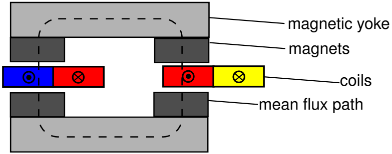
- Based on the Double-rotor Radial Flux Air-cored Permanent Magnet (DRFAPM) machine
- Key feature of the DRFAPM machine:
  - thinner rotor iron yoke required than a Double-rotor Axial Flux Air-cored Permanent Magnet (DAFAPM) machine
  - non-overlapping, air-cored windings
- Benefits of the DRFAPM machine:
  - lighter machine for the same rating DAFAPM machine
  - lower end-turn losses than for overlap windings
  - zero stator iron/core losses
  - zero cogging torque

The IDRFAPM Machine (cont...)

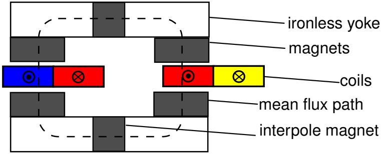
- Key *new* feature of the IDRFAPM machine:
  - makes use of a non-magnetic rotor iron yoke compared to the DRFAPM machine
- Benefits of the IDRFAPM machine:
  - even lighter machine for the same rating DRFAPM machine
- Possible applications of the IDRFAPM machine:
  - extremely efficient and light hub-drive motor
  - extremely efficient and light direct-drive wind generators

The IDRFAPM Machine (cont...)

- The difference between a DRFAPM and a IDRFAPM machine:
  - The DRFAPM has magnetic (iron) yokes to complete the flux path

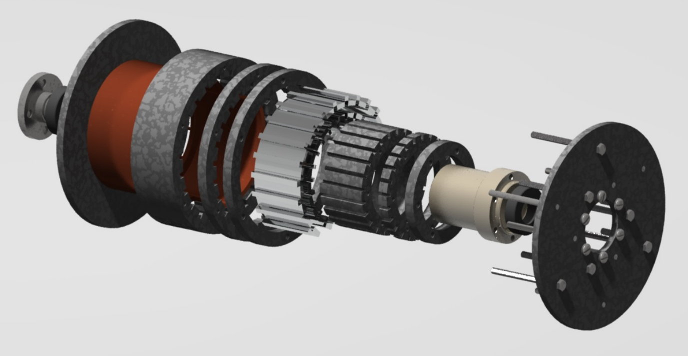


  - The IDRFAPM uses interpole magnets to complete the flux path

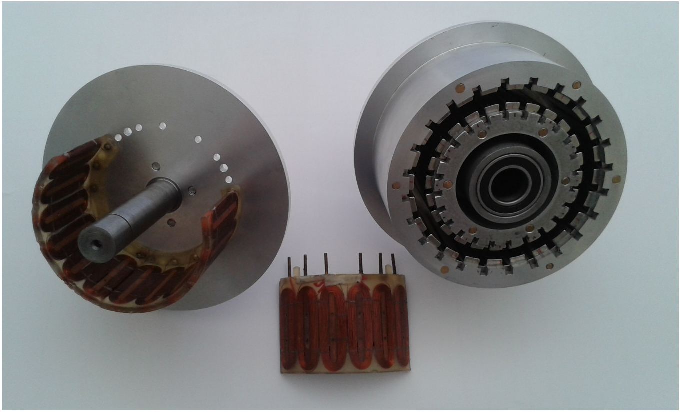


IDRFAPM Aluminium Prototype 1

- Prototype 1 – G.I. Oosthuizen, B.Eng. Final Year Project (2013)

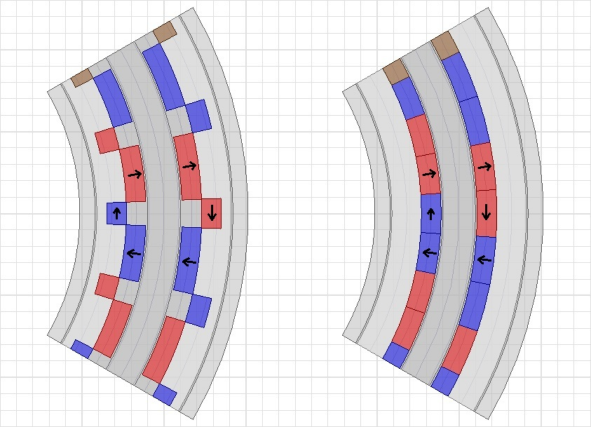


IDRFAPM Aluminium Prototype 1 (cont...)



IDRFAPM Design Review 1

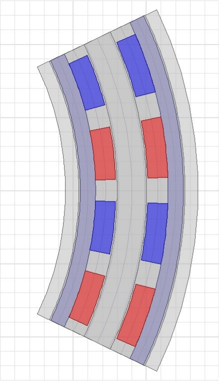
- Design Review – G.I. Oosthuizen, M.Eng. (2014)



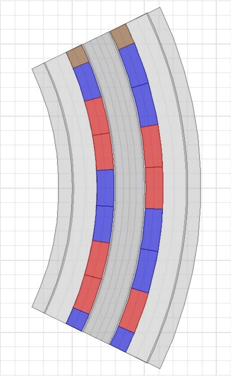
Interpole   Quasi Halbach Array

IDRFAPM Design Review 1 (cont...)

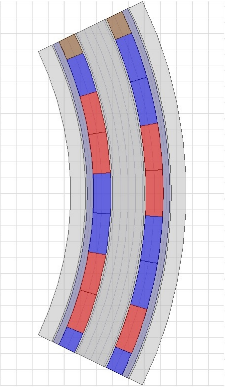
- Three different topologies compared



Steel yoke



Ironless



Hybrid

IDRFAPM Design Review 1 (cont...)

- Torque mass density was calculated for an arbitrary operating point and with the same stator winding configuration, to compare the three topologies:
  - 17 A peak stator current per phase
  - 24 Nm developed torque

IDRFAPM Design Review 1 (cont...)

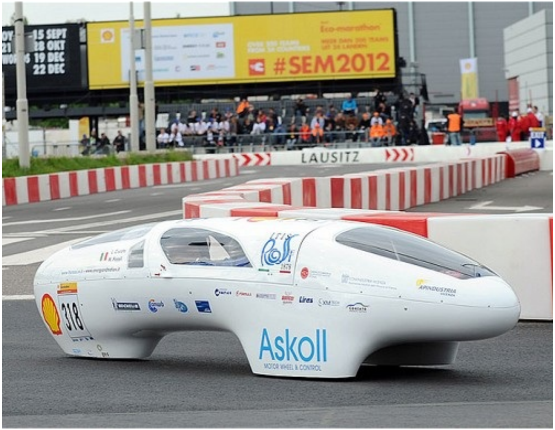
Topology	Magnet Mass(kg)	Total Active Mass(kg)	Torque Density($\frac{Nm}{kg}$)
Steel-yoke	2.19	6.15	3.90
Ironless	2.71	4.22	5.68
Hybrid	2.44	5.24	4.58

For the Ironless Machine

- Torque density is nearly 25% higher than for the hybrid topology with 11% more magnet mass.
- and 45% higher than for the steel-yoke with 24% more magnet mass.

The Shell Eco Marathon (SEM)

- IDRFAPM machine is ideally suited to for a competition like the SEM, when the car with the highest efficiency wins. . .

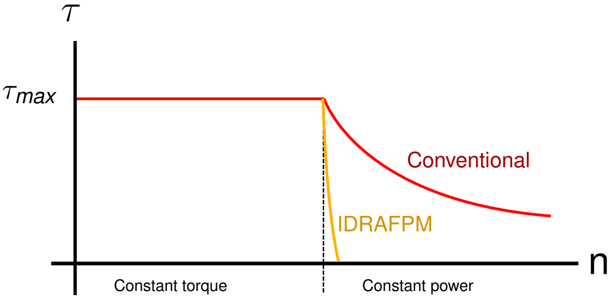


The Shell Eco Marathon (SEM) (cont...)

- Or, for solar race like the Sasol Solar Challenge...

The Shell Eco Marathon (SEM) (cont. . .)

- However, due to the almost square safe operating area of the IDRFAPM machine is beter suited to the SEM competition, due to the lower speed requirements. . .



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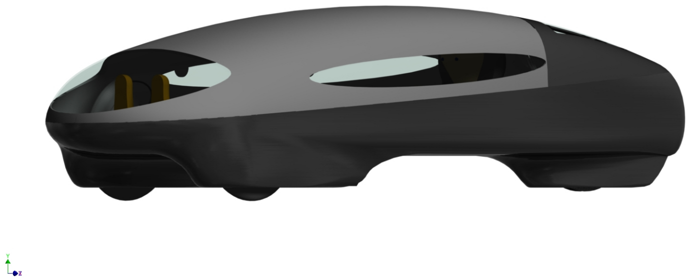
The Shell Eco Marathon (SEM) (cont...)

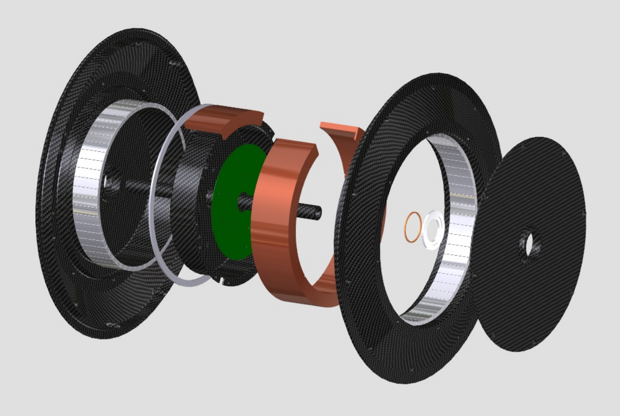
- The SEM vehicle and racetrack dictated the design specifications for the new prototype:

Avg. Speed	RPM	Max. Torque	Voltage
29 kph	300	30 Nm	48 V



IDRFAPM Carbon Fibre Prototype 2

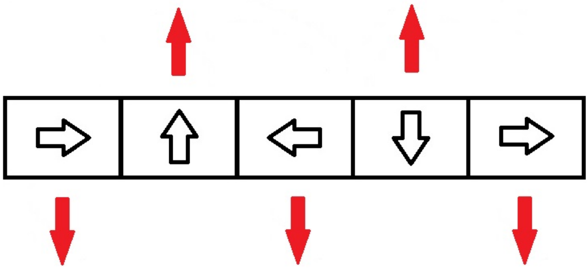
- Due to the IP involved and with the help of Innovus, we got TIA funding to pursue our next prototype, using Carbon Fibre



IDRFAPM Carbon Fibre Prototype 2 (cont...)

IDRFAPM Design Revision 2

- We are making use of Neodymium NdFeB 48 permanent magnets
- Which are extremely strong magnets
- And do not like being placed in a quasi Halbach configuration

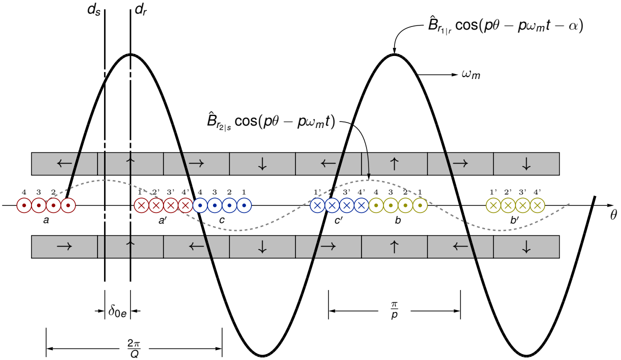


IDRFAPM Design Revision 2 (cont...)

- Which we experience first hand during assembly...

IDRFAPM Design Revision 2 (cont…)

- Due to the iron-less stator, the flux-density in the stator is almost sinusoidal



- This has a lot of advantages…

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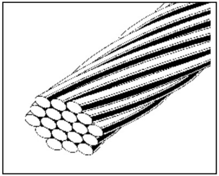
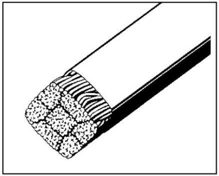
IDRFAPM Design Revision 2 (cont...)

- But unfortunately also results in eddy current losses in the copper windings.
- Initial estimates for our 1.6 mm^2 were completely incorrect

$$
\begin{aligned}
P_{eddy} &= 1.7\, N\, Q\, a \left(\frac{\pi l d^4 \hat{B}^2_{r_{1|r}} \omega_e^2}{16 \rho_{cu}} \right) \\
&= 185\ \mathrm{W}
\end{aligned}
$$

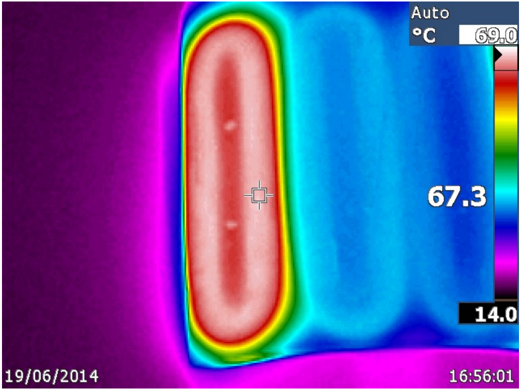
- These eddy losses can however be minimized by using Litz wire ($70 \times 0.2\,\mathrm{mm}^2$)





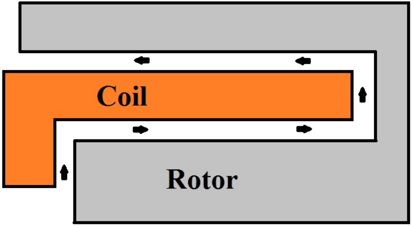
IDRFAPM Design Revision 2 (cont…)

- The increased current density has also raised questions regarding the cooling of the air-cored stator coils



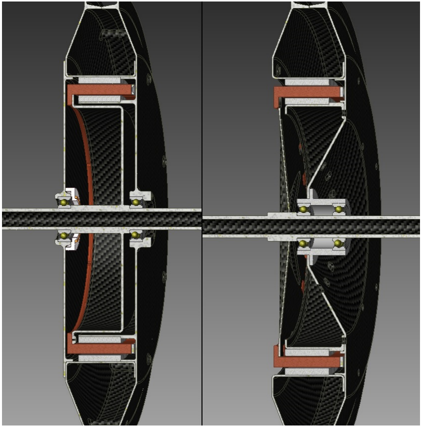
IDRFAPM Design Revision 2 (cont...)

- Thermal modelling is an approximation at best.
- Investigate the possibility and effect of forced convection.
- Effects will be measured by thermistors embedded in coils.



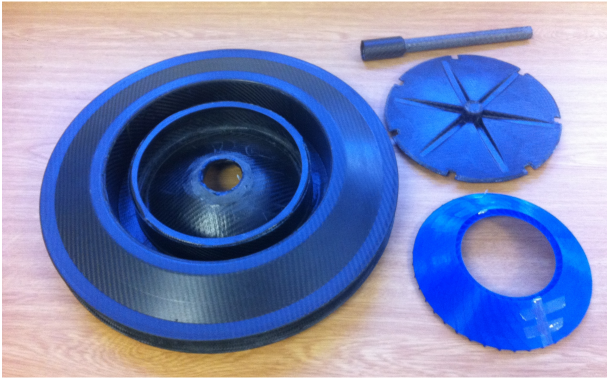
IDRFAPM Design Revision 2 (cont...)

- During assembly we also picked up that our bearing design does not work as anticipated



Current & Future Work

- Complete 3rd prototype.



- Do thorough lab testing regarding efficiency, (thermal) rating, etc.

Current & Future Work (cont...)

- Development of a power electronic converter for our IDRFAPM machine
- Development of a Li-Ion battery storage with integrated Battery Management Systemm (BMS) to complete the “whole package deal” for the IDRFAPM machine
- Investigate the use of the IDRFAPM machine for wind turbine applications, especially VAWT

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