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Publication date:
2013

Document Version
Publisher's PDF, also known as Version of record

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Citation (APA):
Högberg, S., & Jensen, B. B. (2013). Reducing Usage of Permanent Magnet Material in Magnetic Couplings Using Finite Element Analysis. Sound/Visual production (digital), Technical University of Denmark, Department of Electrical Engineering.

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Reducing Usage of Permanent Magnet Material in Magnetic Couplings Using Finite Element Analysis

Stig Högberg, **Bogi Bech Jensen**

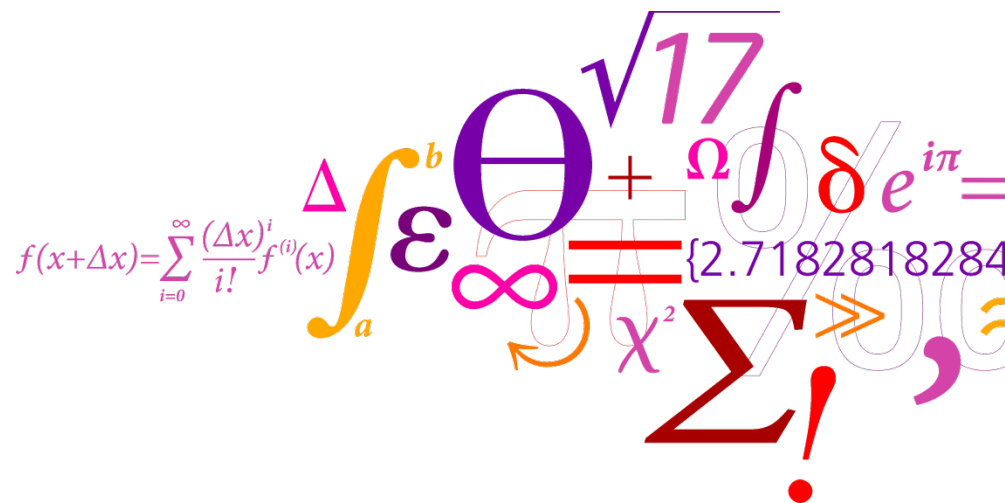
¹ Department of Electrical Engineering, Technical University of Denmark, Denmark

24-10-2013

Applied Magnetic Materials 2013

Pori, Finland

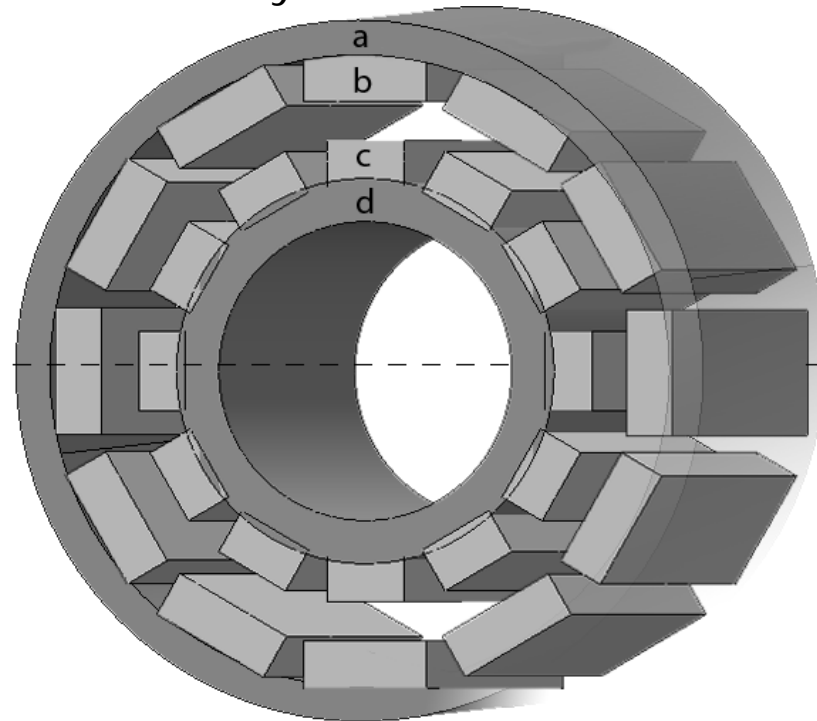
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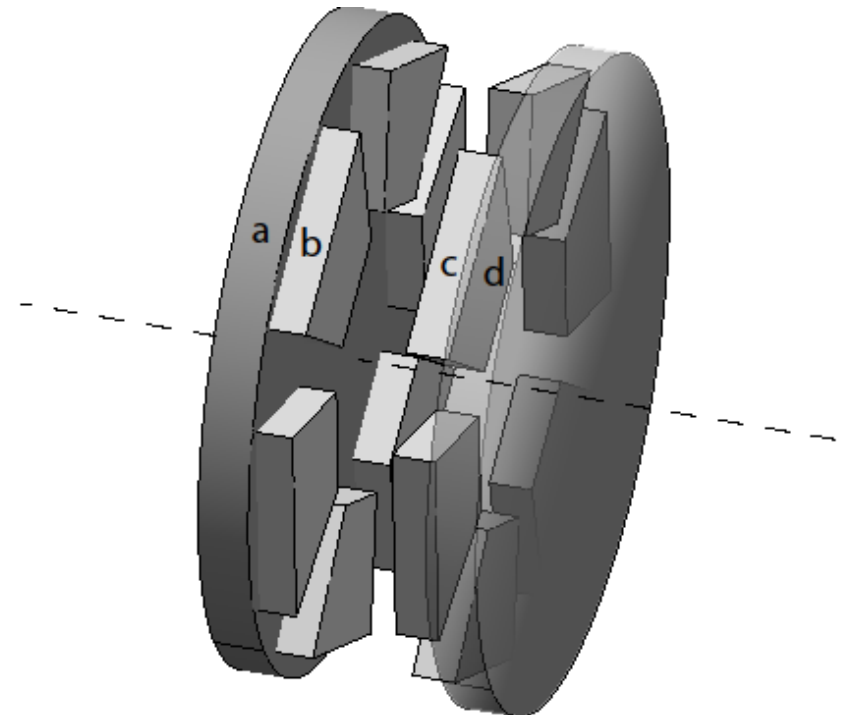
Motivation – Why Permanent Magnet Couplings?

- Contact-less torque transfer
 - Ideal in low maintenance systems
- Sacrificial coupling (overload protection)

Cylindrical PMC

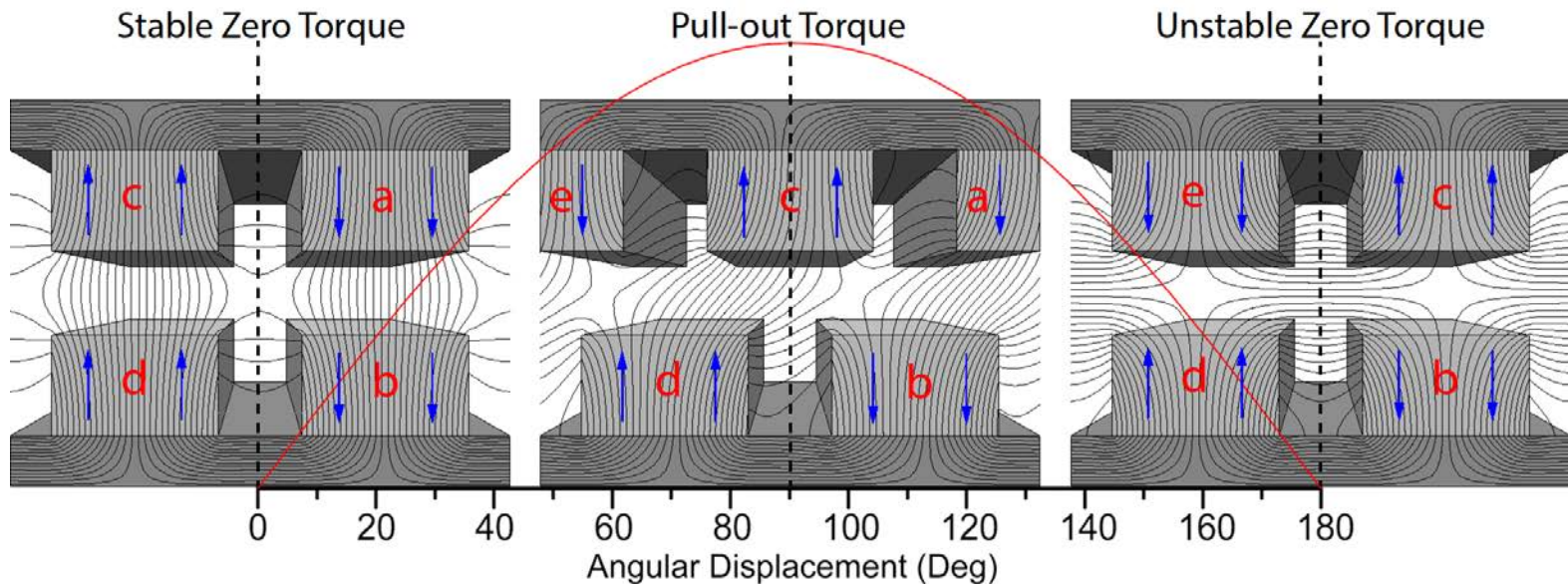


Disk-type PMC



Static Torque In a PMC?

Static torque as a function of angular displacement in a flat PMC representation.



Design objective:
Maximum torque per
kilogram magnet

$$TPKM = \frac{T_{po}}{V_{mag} \cdot \rho_{mag}}$$

Pull-out Torque $\leftarrow T_{po}$
 Magnet Volume $\leftarrow V_{mag}$
 Mass density $\leftarrow \rho_{mag}$

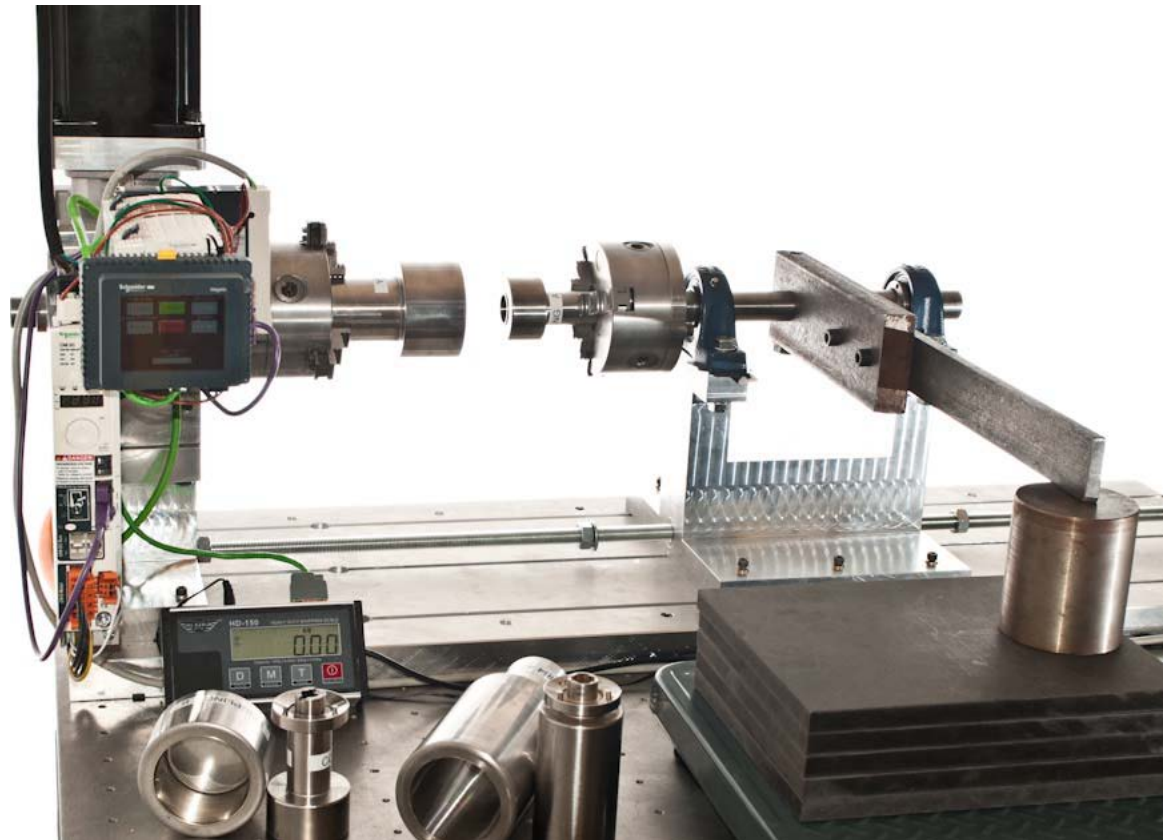
Designed Test-Rig For Static Torque Measurements

Hardware

- Servo-motor (24 Nm)
- Gearbox (1:10)
- Servo-drive + PLC
- Scale with RS232
- Self centring chucks

Automated

- Touch panel input for control
- Locate zero torque position
- Measurements are stored on USB pen-drive

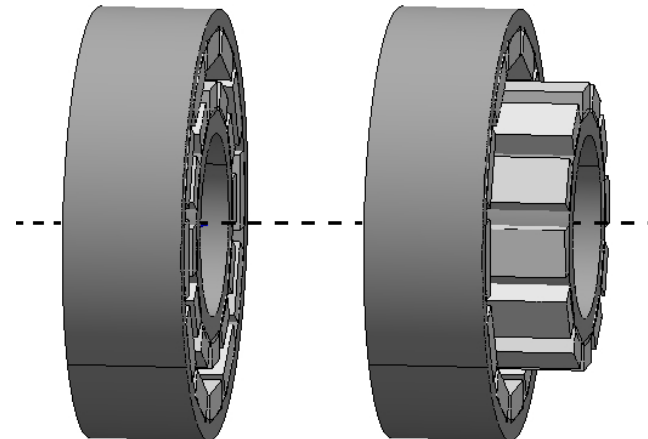


High Accuracy Alignment System

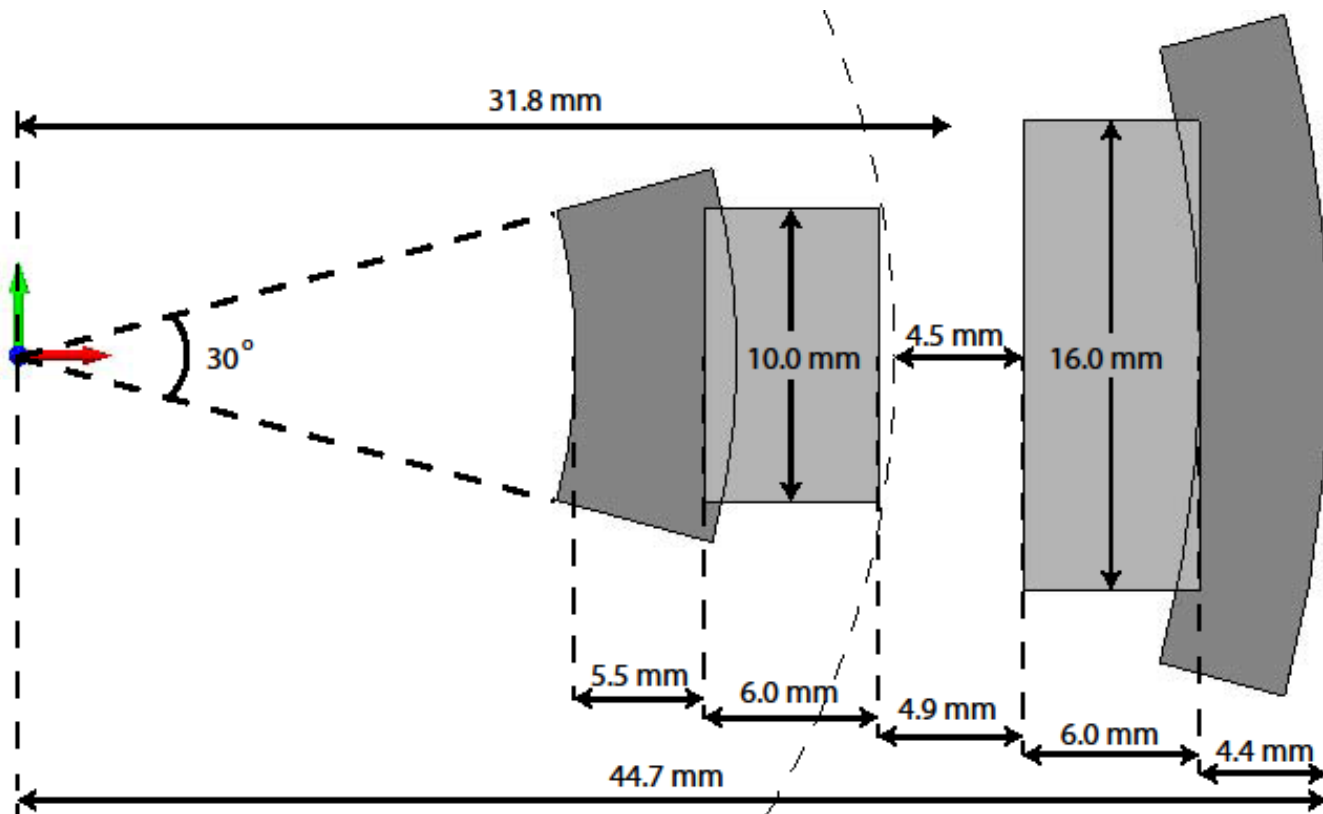


PMC Specification For a 1-row PMC

Type	Cylindrical	Poles	12
B_r	1.21 T	H_c	$-891 \frac{kA}{m}$
Mean Air-gap radius	31.8 mm	Magnets	Nd-Fe-B
Active axial length	25.0 mm	Pull-out torque	14.3 Nm

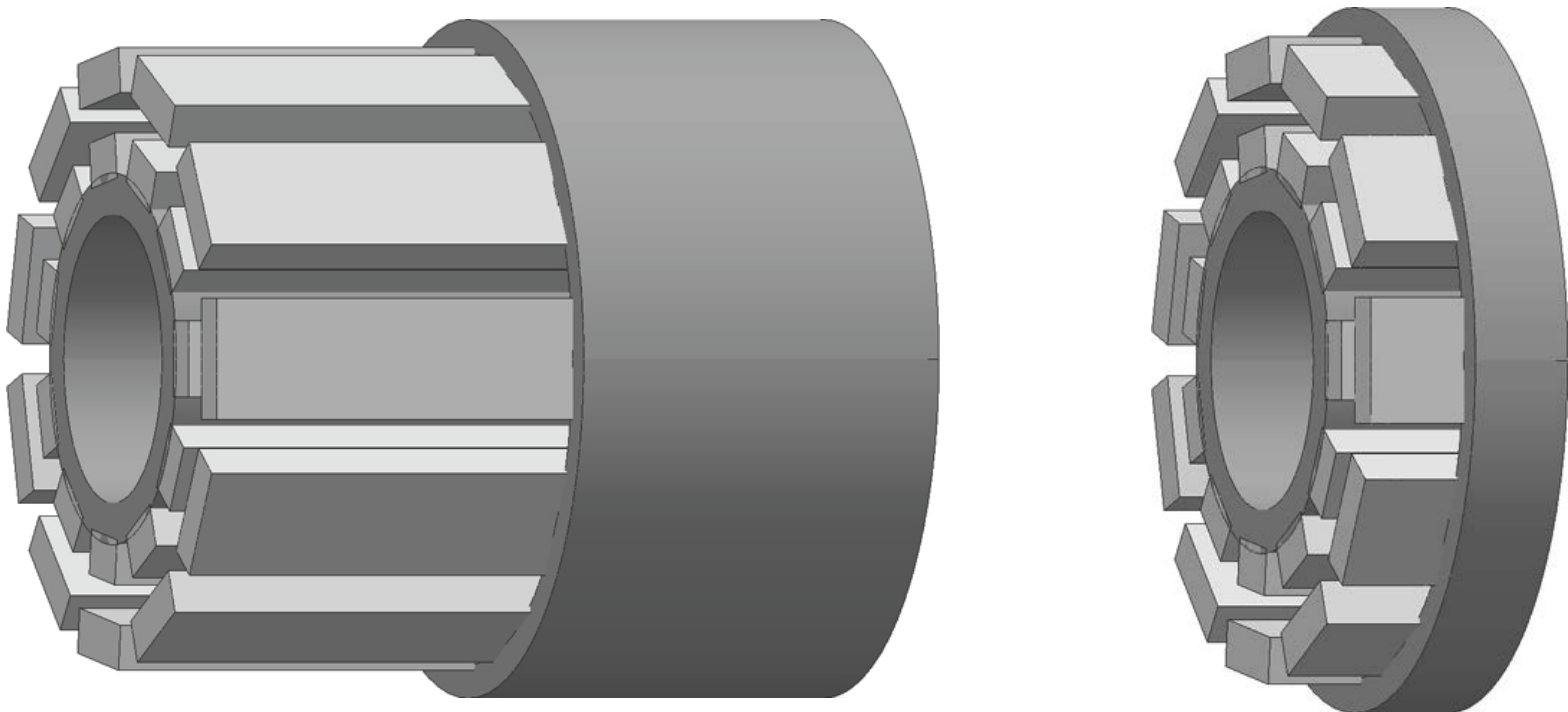


Dimensions of PMC



1-row PMC And 4-row PMC

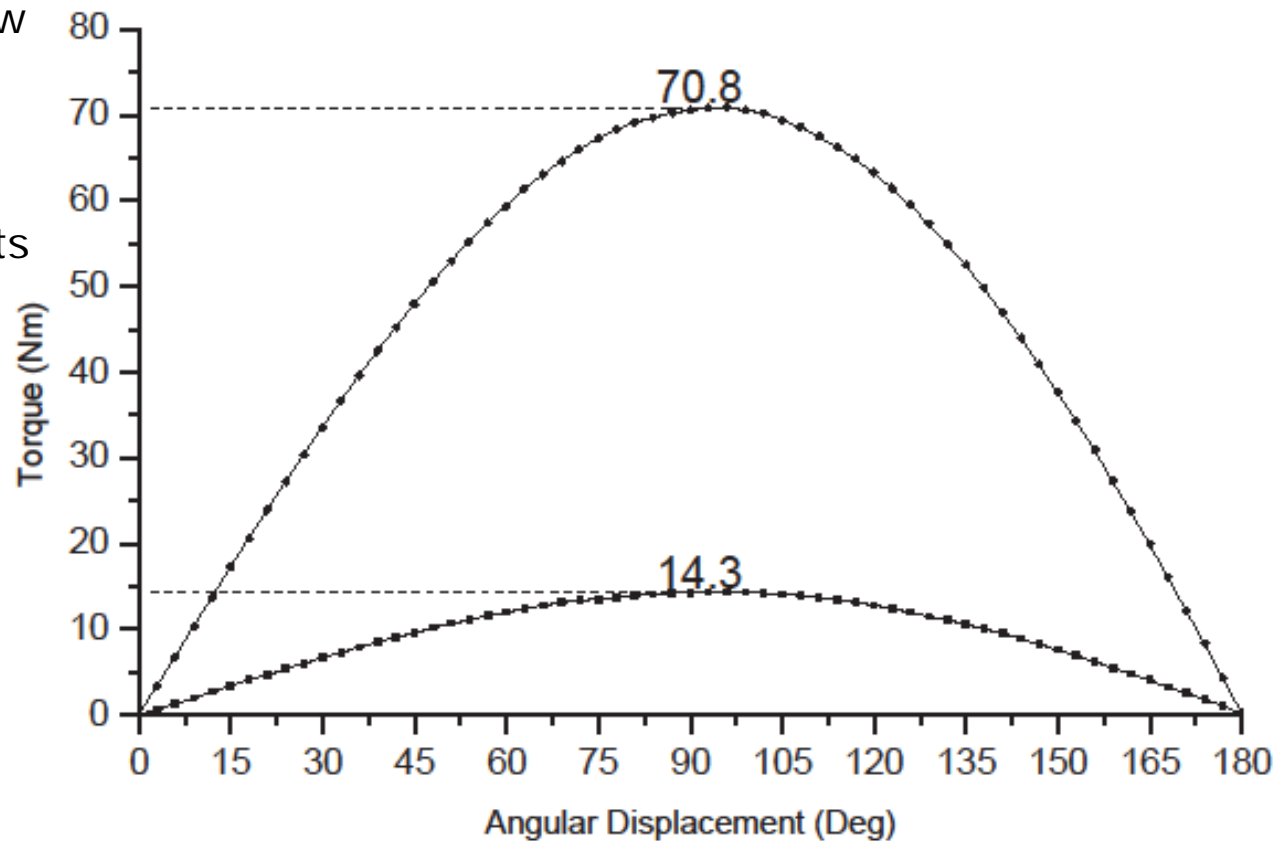
The 4-row has an active axial length of 100 mm compared to 25 mm of the 1-row PMC



Experimental Results of Static Torque

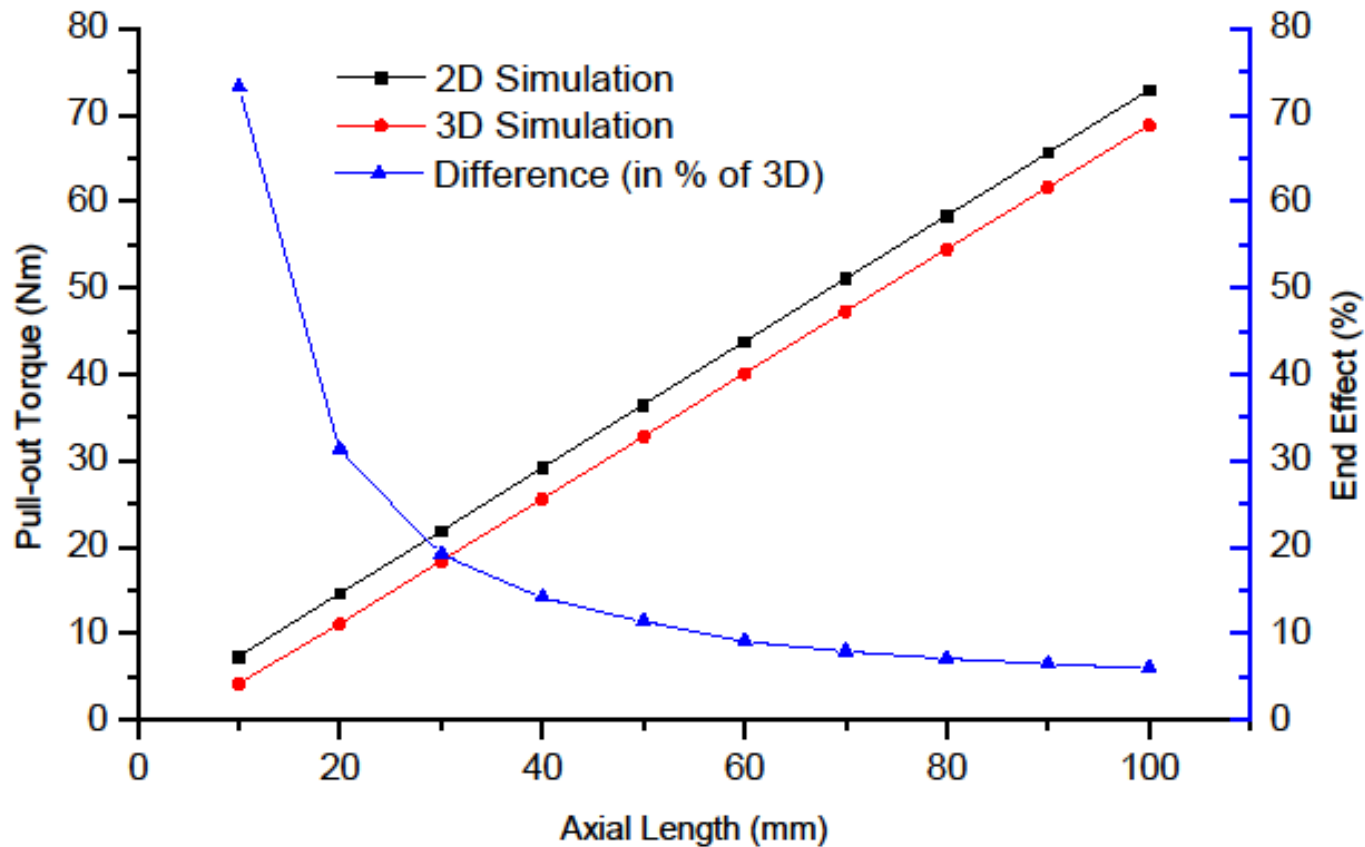
Pull-out torque of 4-row PMC is almost 5 times that of the 1-row PMC.

This is due to the influence of end-effects



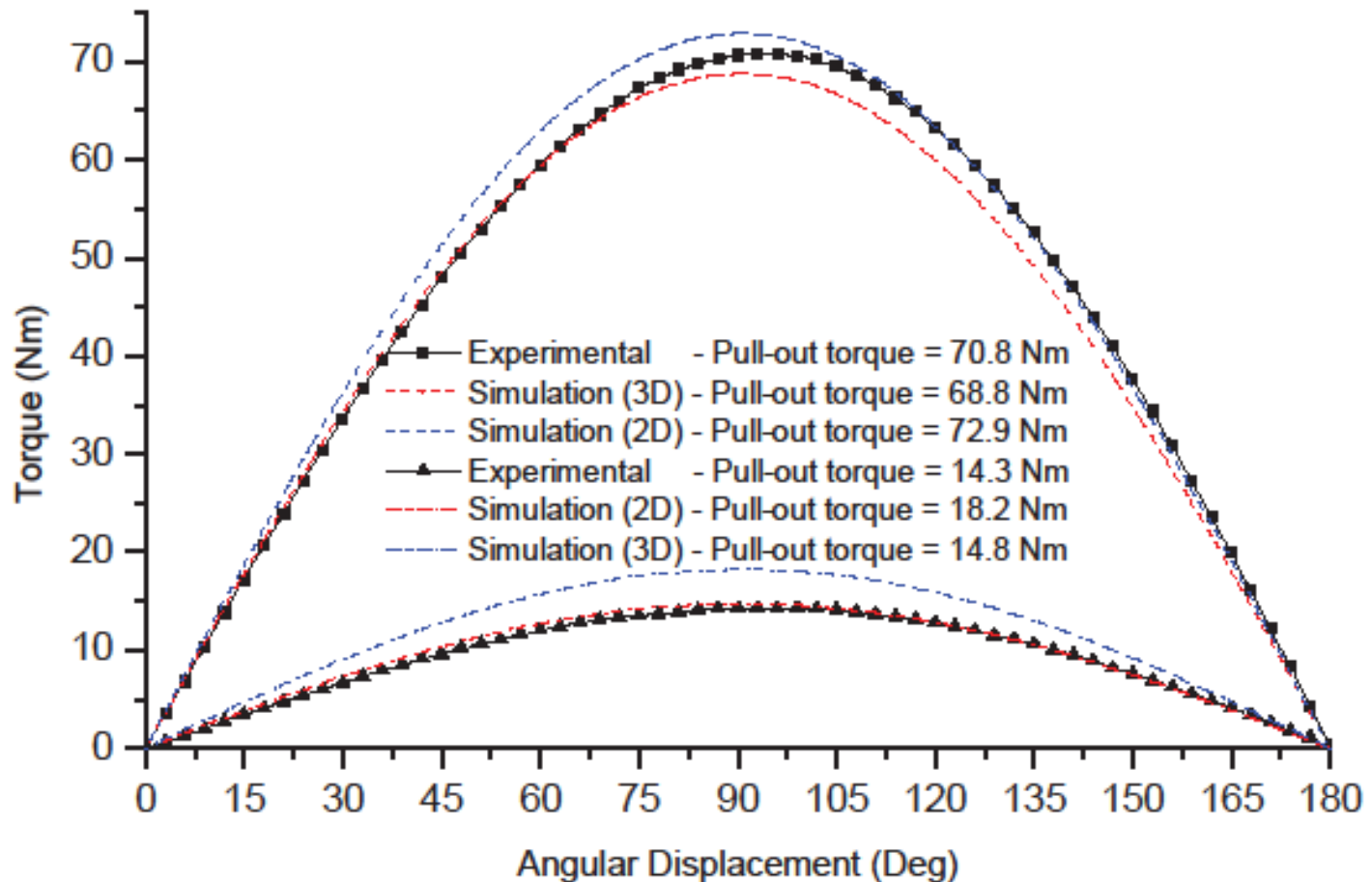
End-Effects, Explored By FEA

- End effects are significant if the PMC is short



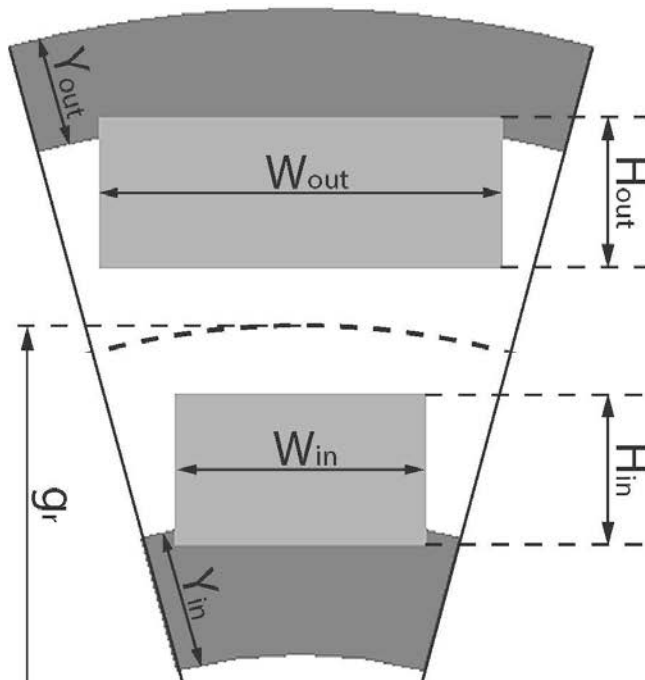
Comparing Experimental and Simulation

- Simulations are based on 3D FEA

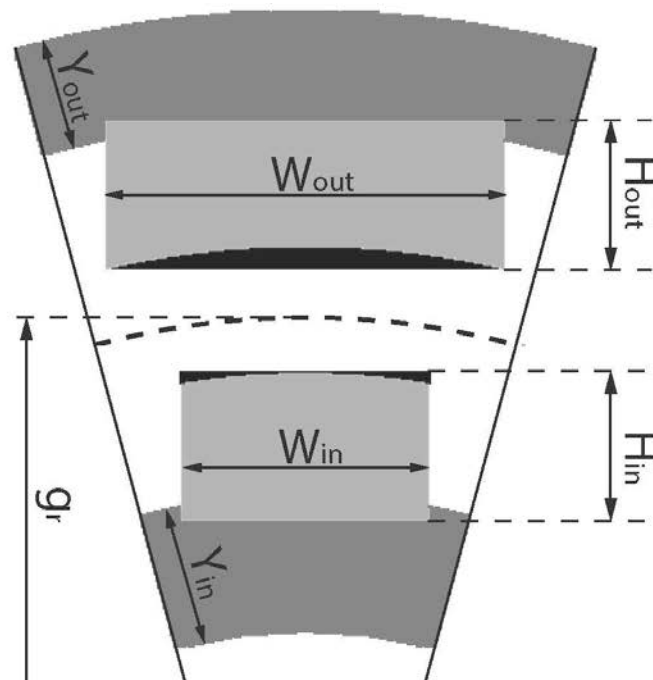


Introducing Two PM Shapes

Rectangular PMs
(original)



Concave / Convex PMs
(new)



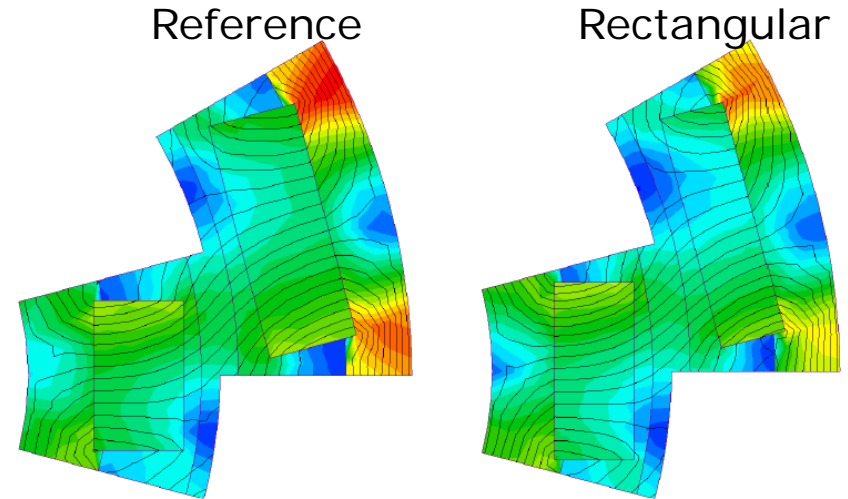
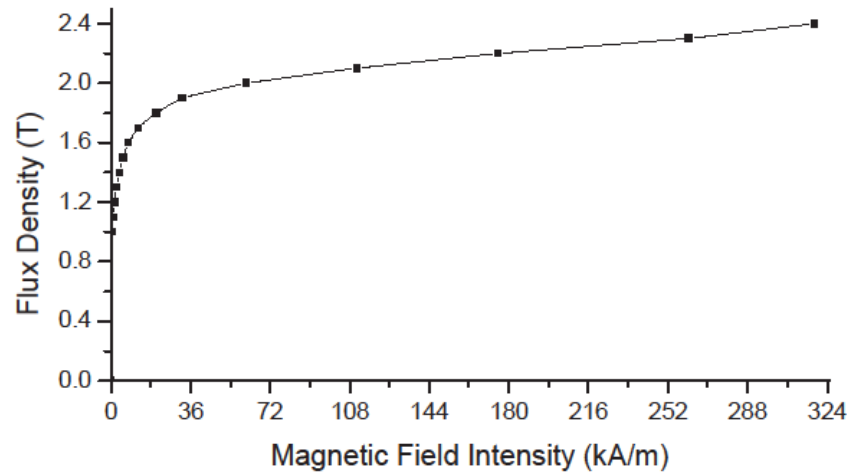
Automated Design Simulation

Controlling model parameters in Infolytica MagNet Through Matlab script

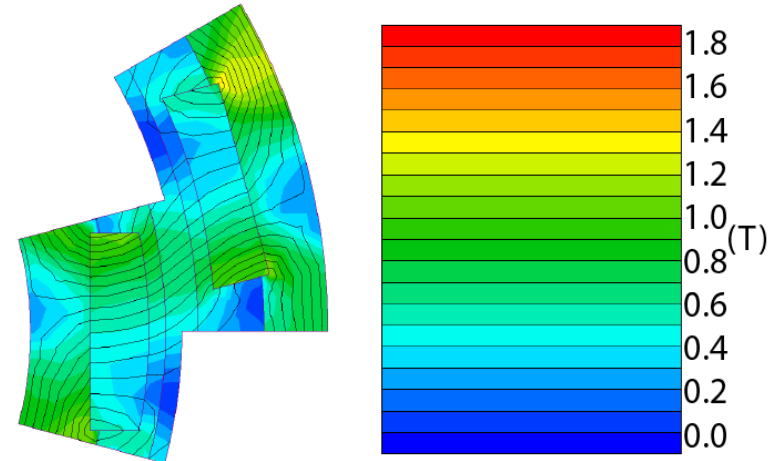
<i>Variable</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Increment</i>	<i>Best Design</i>	
Rectangular Magnets					
H_{in}	5.0 mm	6.2 mm	0.2 mm	5.4 mm	
H_{out}	4.0 mm	5.4 mm	0.2 mm	4.4 mm	
W_{in}	10.0 mm	13.5 mm	0.5 mm	12.0 mm	
W_{out}	15.5 mm	18.0 mm	0.5 mm	16.0 mm	
Pull-out Torque				14.8 Nm	
TPKM				48.6 Nm/kg	
TPKM Increase				15.6%	
Concave/Convex Magnets					
H_{in}	3.2 mm	5.8 mm	0.2 mm	4.0 mm	
H_{out}	3.2 mm	5.8 mm	0.2 mm	4.0 mm	
W_{in}	10.0 mm	14.0 mm	0.5 mm	13.5 mm	
W_{out}	12.0 mm	17.0 mm	0.5 mm	13.5 mm	
Pull-out Torque				14.8 Nm	
TPKM				66.2 Nm/kg	
TPKM Increase				57.6%	
Reference PMC					
H_{in}	6.0 mm	H_{out}	6.0 mm	W_{in}	10.0 mm
				W_{out}	16.0 mm
Pull-out Torque				14.8 Nm	
TPKM				42.0 Nm/kg	

Further Steps

- The core-back of the both rectangular and concave / convex (best) designs could be optimised to further increase the torque per kg magnet.



Concave / Convex



Conclusion

- 3D FEA simulations were found to accurately calculate the static torque:
 - 2D is inaccurate since end-effects are not included
 - This is less pronounced in longer couplings
- Design of PMC with two different PM shapes were presented:
 - Rectangular and concave / convex
 - TPKM increase of rectangular: 15.6%
 - TPKM increase of concave / convex: 57.6%
- Further investigation could lead to even better results:
 - Core-back thickness could be decreased
 - Prototyping of the couplings
- Thank you

References and further reading

- S. Hogberg, B. B. Jensen, F. B. Bendixen, "Design and Demonstration of a Test-Rig for Static Performance-Studies of Permanent Magnet Couplings," *IEEE Transactions on Magnetics*, Vol. , No. , pp. , 2013.
<http://dx.doi.org/10.1109/TMAG.2013.2274645> (early access)
- S. Högberg, B. B. Jensen, F. B. Bendixen, "Improving Torque per Kilogram Magnet of Permanent Magnet Couplings using Finite Element Analysis," *IEEE International Electric Machines and Drives Conference (IEMDC2013)*, Chicago, Illinois, USA, May 2013.
<http://dx.doi.org/10.1109/IEMDC.2013.6556229>

Acknowledgements

- Danish Ministry of Science, Innovation and Higher Education



- Envision Energy



- Sintex

