Designing robust electrical machines FUTURE Vehicles WP2.2

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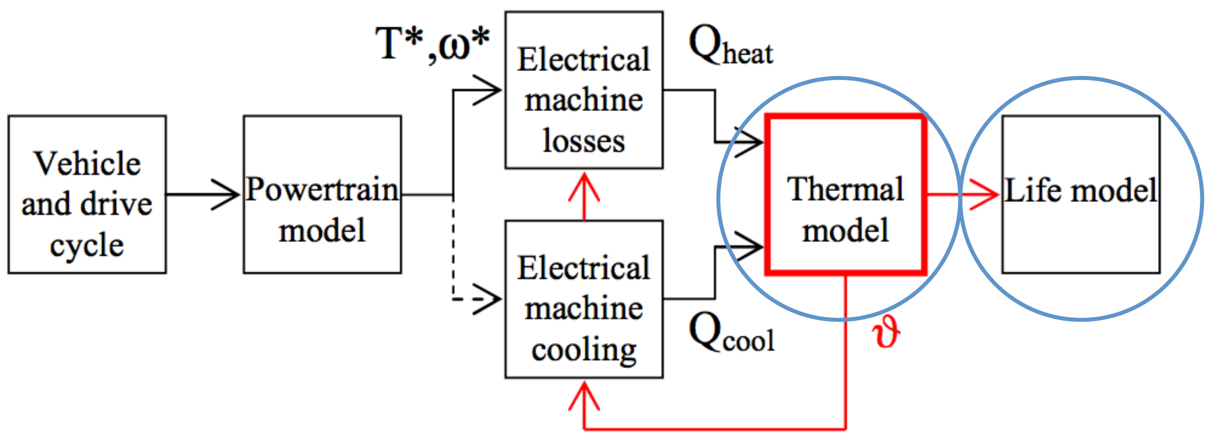
WP2.2 Aims

- Investigate operating machines closer to limits
- Requires better understanding of failure mechanisms
- Focus: thermal and electrical stressing
- Aim to develop approaches for diagnosis and prognosis

- Deliverables: detailed database of models including ageing and degradation, and identified gaps in knowledge

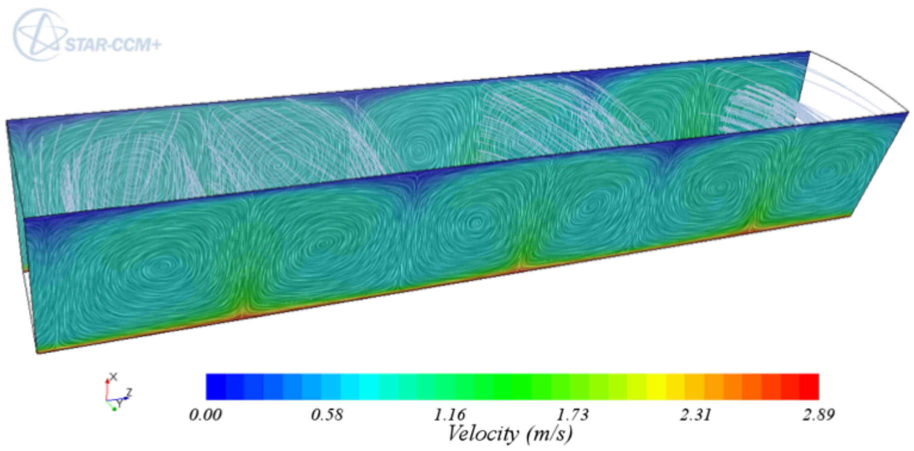


From Huang et al, "Dynamic Thermal Modeling and Application of Electrical Machine in Hybrid Drives", ICEM 2014, Berlin.

Thermal modelling

- Generally well understood, but..
  - Convection is challenging
  - Thermal contact resistance may be unknown
- We are investigating these thought this and other similar projects (e.g. ADEPT http://www.adept-itn.eu)

CFD Simulation of Taylor vortices in an electrical machine airgap:



Romanazzi P and Howey DA, "Air-gap convection in a switched reluctance machine", 10th International Conference on Ecological Vehicles and Renewable Energies EVER2015, IEEE, Monaco, 31/3-2/4 2015.

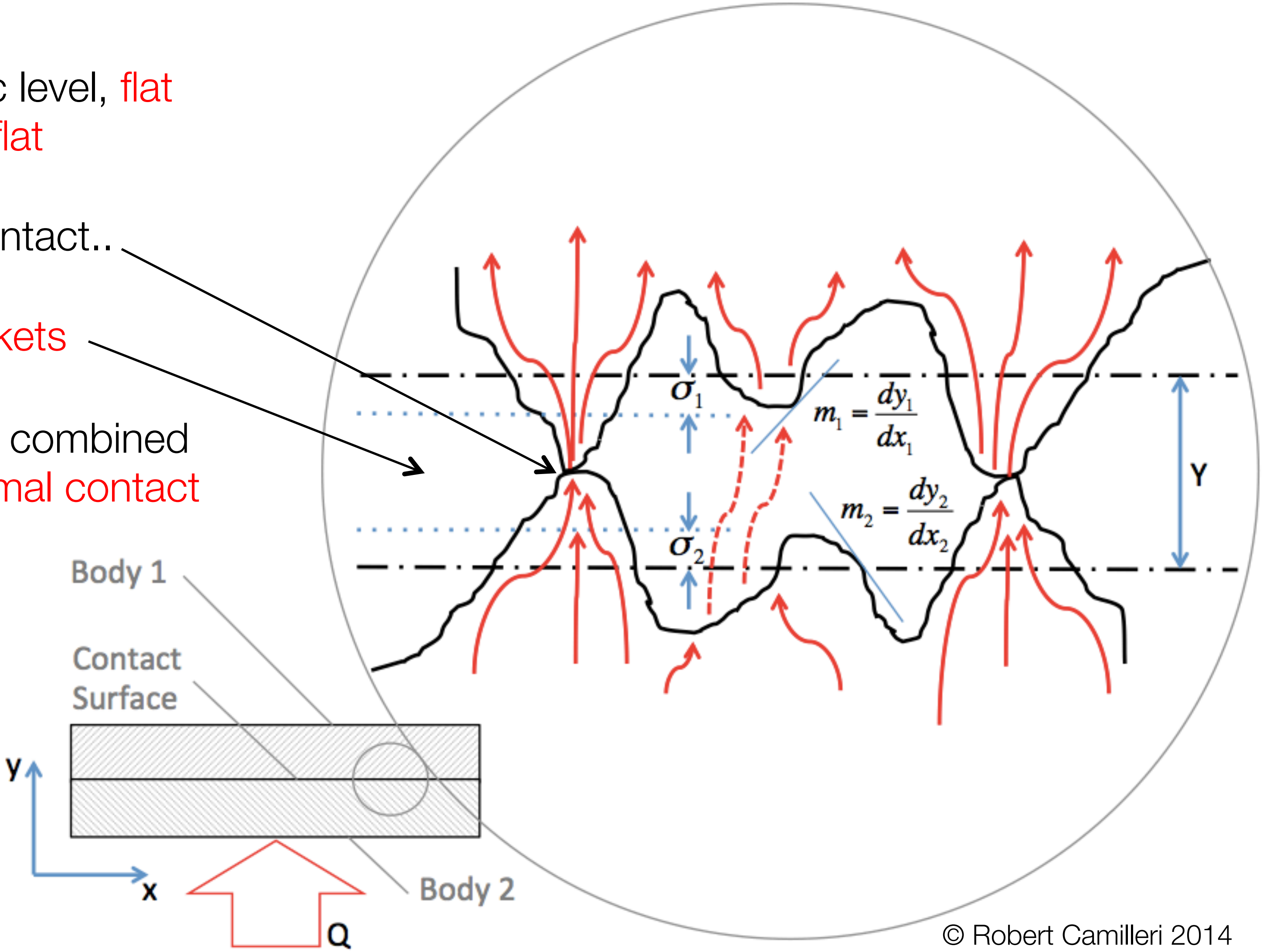
Thermal contact resistance

On a microscopic level, flat surfaces are not flat

There is direct contact..

..but also air pockets

We represent the combined effect with a thermal contact resistance (TCR)

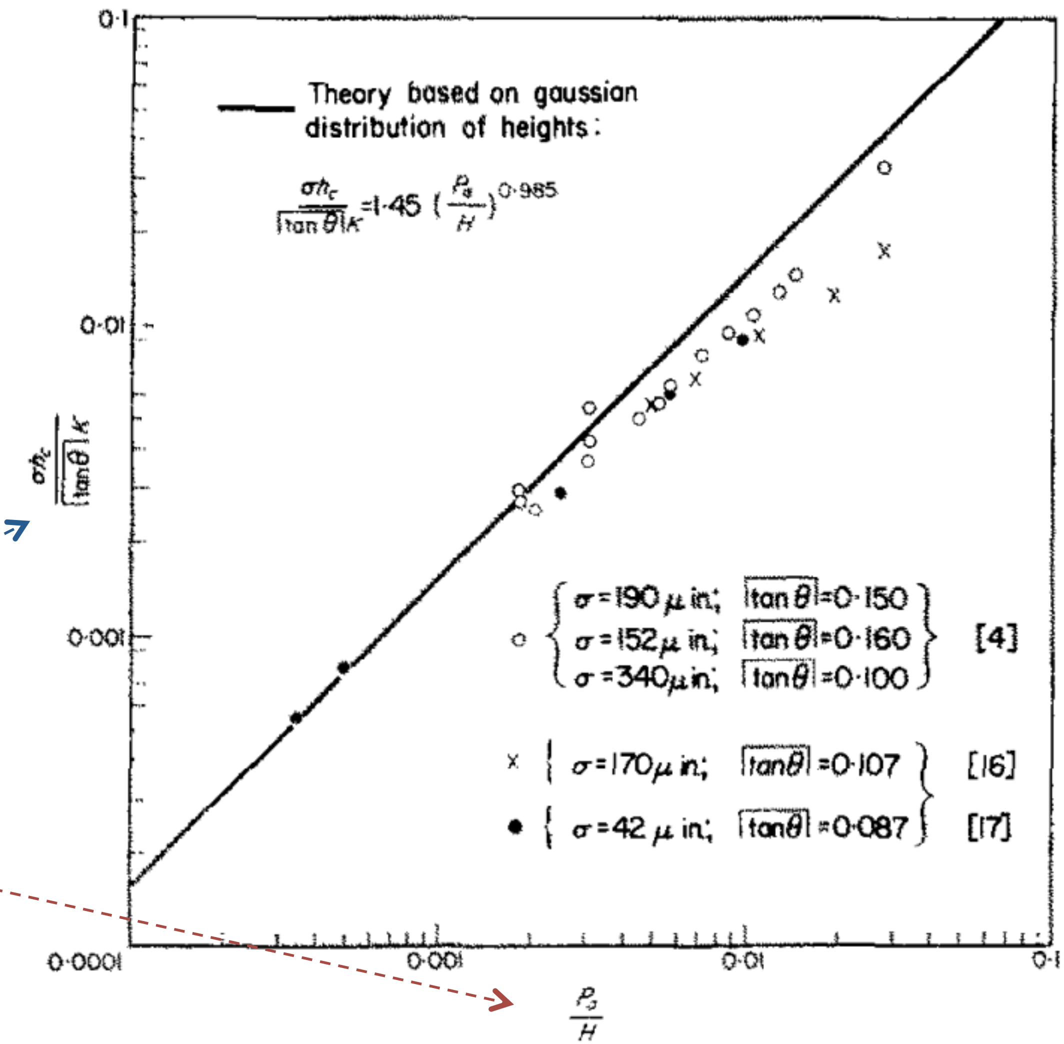


Modelling contact resistance

- Classic model is Cooper, Mikic and Yovanovich (CMY)*
- Gaussian distribution for heights of peaks

$$\frac{h_c}{k}\frac{\sigma}{<|\tan\theta|>} = f\left(\frac{P_a}{H}\right)$$

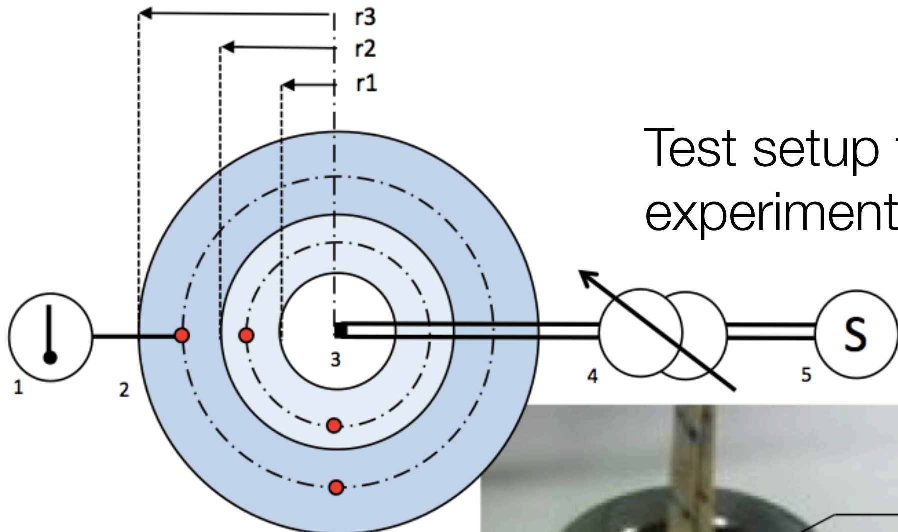
conductance pressure



* Cooper MG, Mikic BB, Yovanovich MM, "Thermal contact conductance", International Journal of Heat and Mass Transfer 12:279-300, 1969

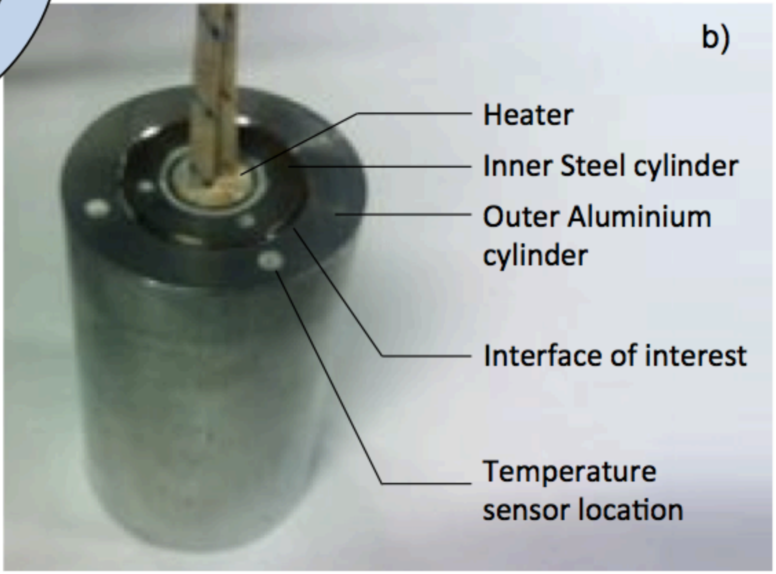
Relevance to electrical machines

- Stator-housing interface
- Copper-slot interface



Test setup for experiments

$$R_{th} = \frac{T_i - T_o}{Q}$$

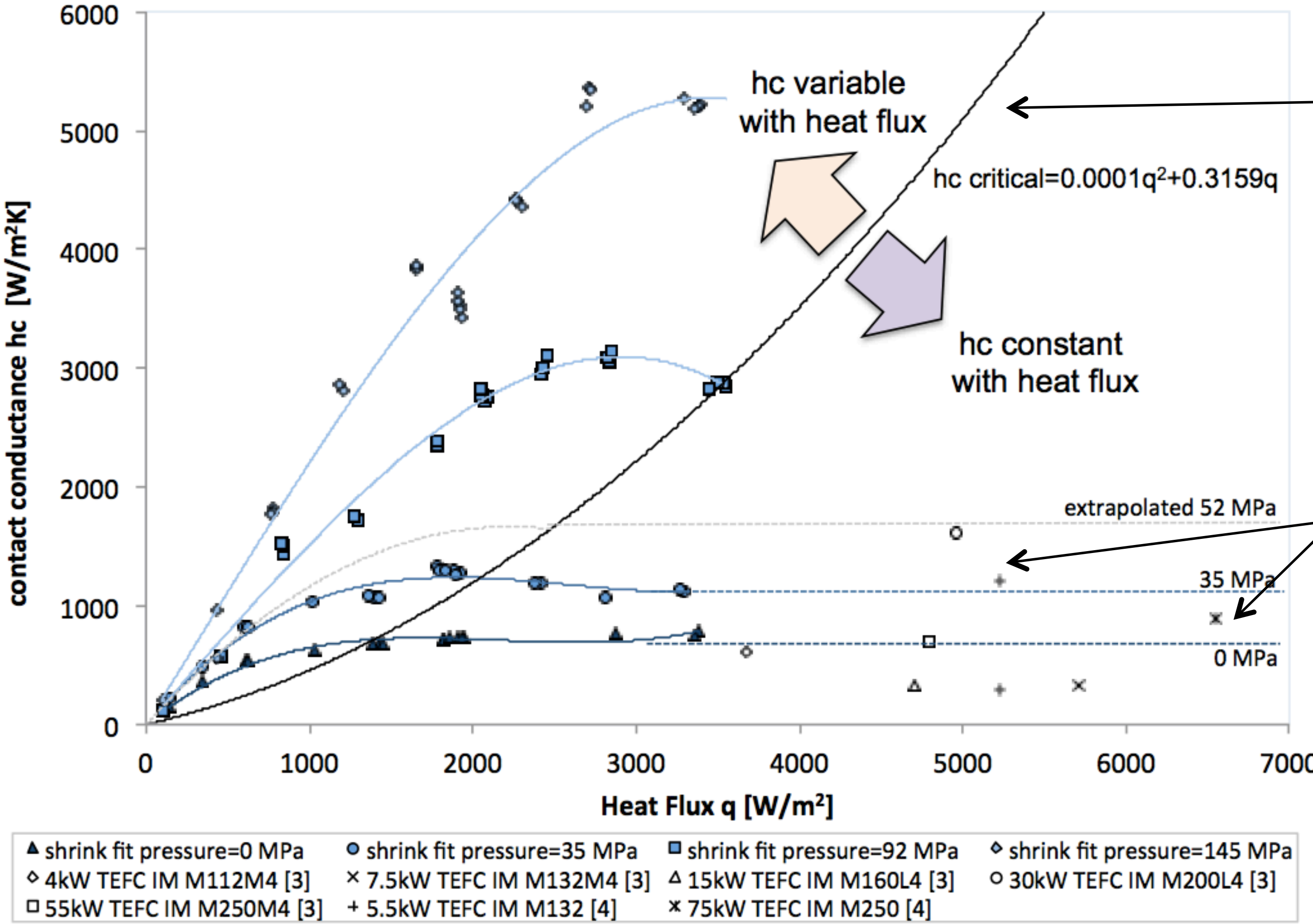


Machine geometry usually concentric therefore contact pressure not constant!

= experimental investigation

Camilleri R, Howey DA, McCulloch MD, "Experimental investigation of the thermal contact resistance in shrink fit assemblies with relevance to electrical machines", IET PEMD, 18-20 April 2014, Manchester UK.

Relevance to electrical machines



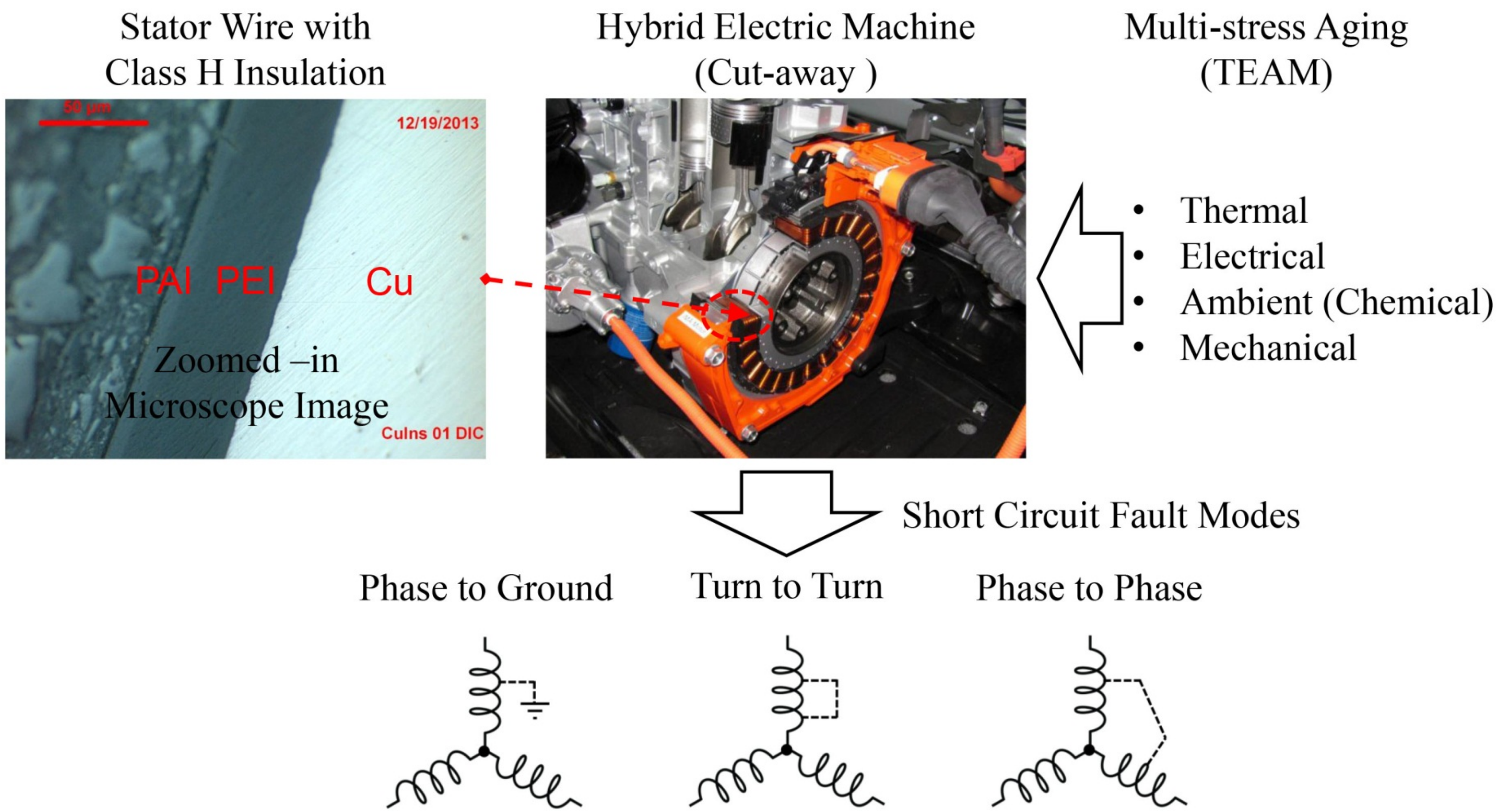
Two zones!

Steady state results from real machines in constant zone, and below tensile limit of aluminium

Camilleri R, Howey DA, McCulloch MD, "Experimental investigation of the thermal contact resistance in shrink fit assemblies with relevance to electrical machines", IET PEMD, 18-20 April 2014, Manchester UK.

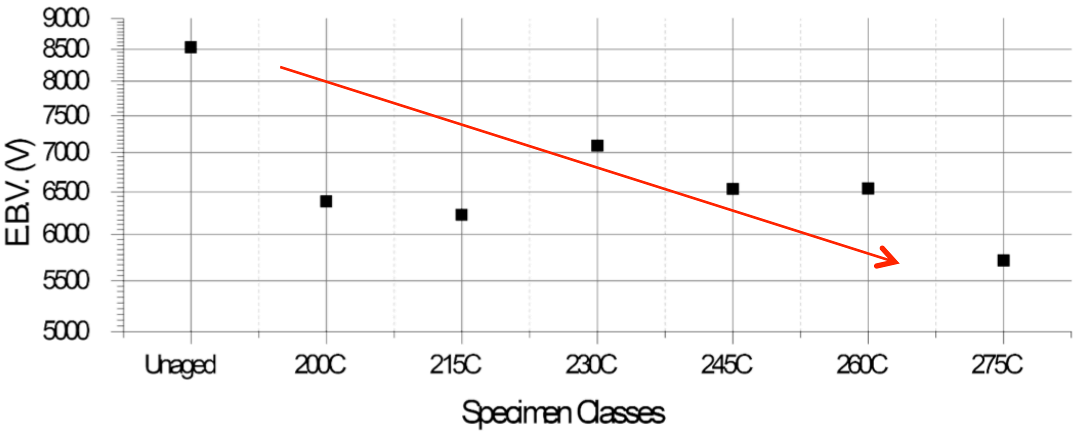
Lifetime modelling

- Initially we investigate impact of temperature on insulation, by measuring impedance, breakdown voltage, mass etc.



Ageing tests

- Long term ageing tests on insulation samples show loss of material, increase in roughness, decrease in breakdown strength, and impedance changes.



Kavanagh DF, McCulloch MD, Howey DA, "Characterisation of Electrical Machine Insulation using Impedance Analysis", IEEE International Symposium on Diagnostics, Power Electronics and Drives SDEMPED13, Valencia, 27-30 August 2013.

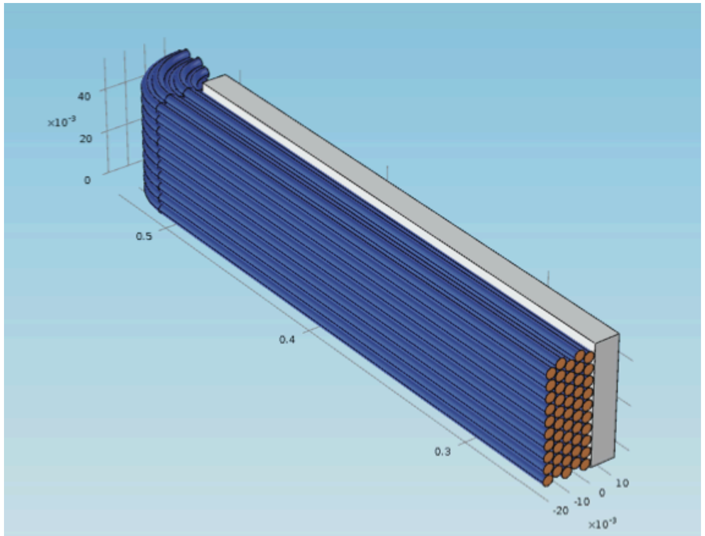
Agbaje O, Kavanagh DF, Sumislawska M, Howey DA, McCulloch MD, Burnham KJ, "Estimation of temperature dependent equivalent circuit parameters for traction-based electrical machines", HEVC 2013.

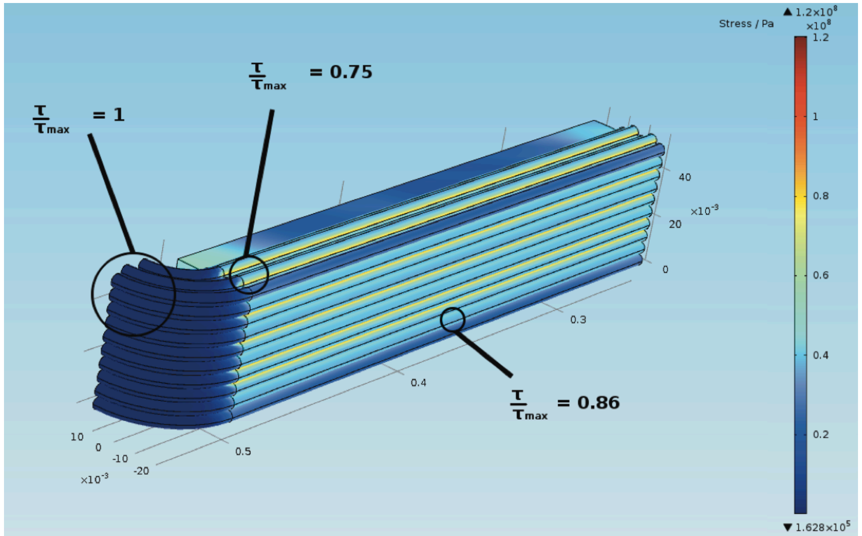
Coupled lifetime modelling

- Temperature and stress can both impact insulation lifetime.
- Zhurkov lifetime model similar to Arrenhius, includes stress:

$$\tau = \tau_0 \exp \frac{U_0 \gamma \delta}{kT}$$

- We constructed coupled thermal-mechanical simulations to predict likely failure point at slot exit:





- Many thanks to Dr Darren Kavanagh, Robert Camilleri, and to our industrial collaborators and sponsors
- I also work on batteries, see http://epg.eng.ox.ac.uk/content/energy-storage

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