Thermally Nonlinear Magnet Modelling Technique using Ansys Maxwell

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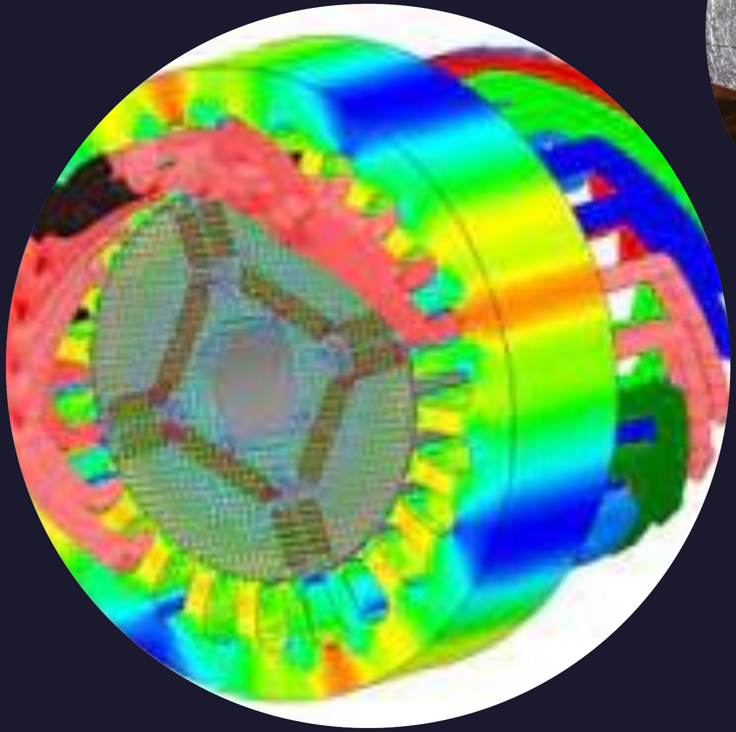
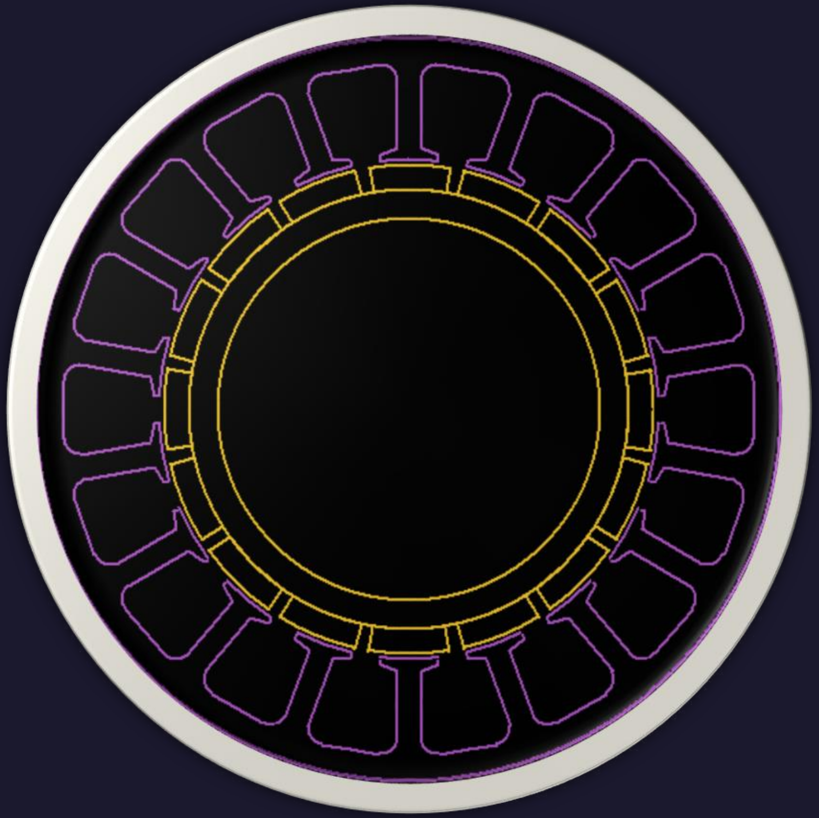
Agenda

- Introduction-Permanent Magnet Motors
- Purpose of the Thermal Analysis
- Thermal Behavior of Permanent Magnets
- Difficulty of Solving Thermally Non-linear Problem Using FEA Tools
- Analytical Model and Implementation in Parametric Solutions
- Validation method and Conclusions



This is a novel simulation technique; validation is required by users for the effective and efficient results.

Introduction-Permanent Magnet Motors



PM BL DC Motor cross-section

- Permanent Magnet motors are widely used in Industries due to its very high torque density, simplistic brushless constructions and high efficiency
- They are used in harsh environments where temperatures are widely changing due to higher ambientes and lower heat dissipation due to its compactness.
- Most of the designers usually incorporate thermal behavior of the resistive elements after one dimensional thermal analysis.

Purpose of the Thermal Analysis

- The applications of permanent magnet includes; Electric Vehicles, Commercial fans and Pumps, Automotive actuators, Robotics, Medical devices, Agriculture, Cooling towers, Industrial processes etc.
- Temperature is highly impacting the resistance of the motor and cause increase in copper losses.
- Temperature also impacts permanent magnet operating point which results in changing the airgap flux density and cause changing the back-emf constant (kV) and Torque constant (kT) of the motor.
- Changing kV/kT will change the operating current at rated out-put conditions and hence increase copper losses.
- One-dimensional thermal analysis for PM motor need to be performed to estimate approximate temperature-rise of windings and magnets.

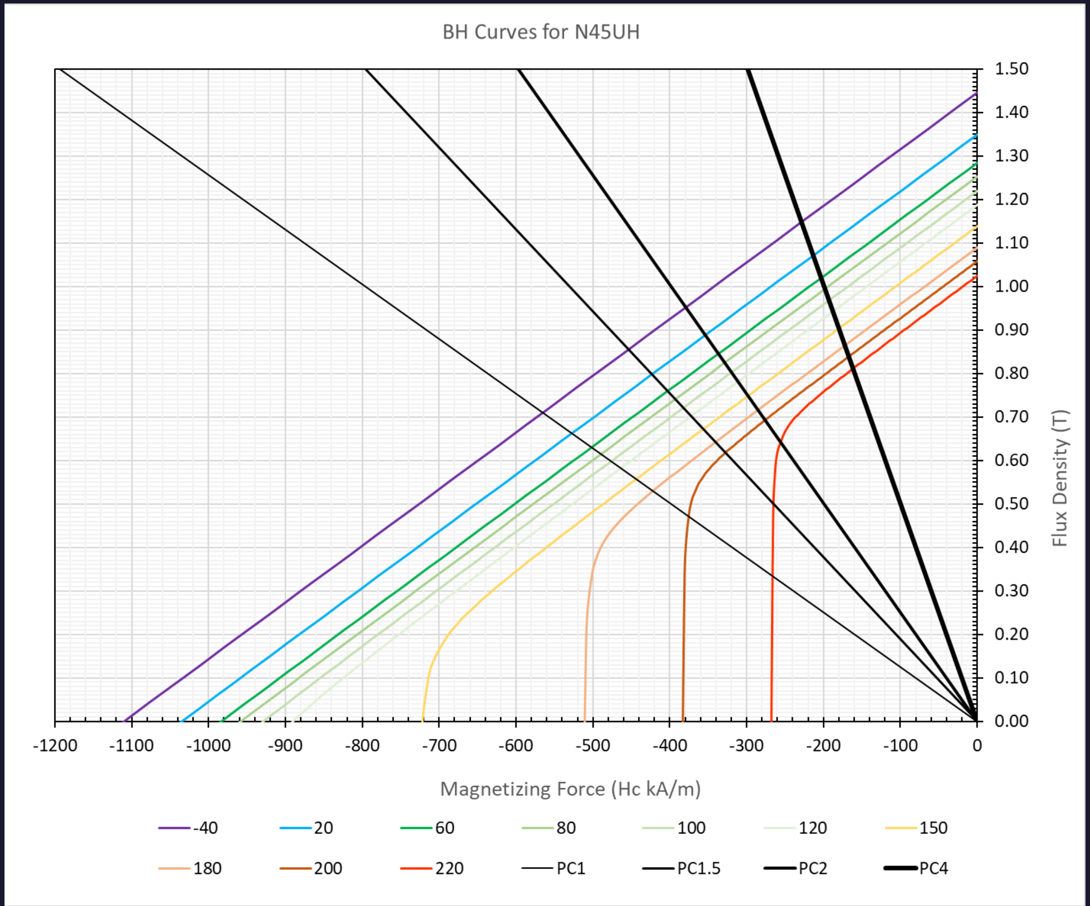
PM BLDC Motor Application to EVs

Thermal Behavior of Permanent Magnets

- Most of the permanent magnets have their reversible temperature coefficients for induction (residual flux density), Br and intrinsic coercivity (Hci).

- Reversible Temperature Coefficient for Induction Br(α); α = Δ Br / Δ T * 100 (%/°C) [ΔT = 20°C – Tx 0°C] Usually negative for all magnets. i.e. Br decreases with increase in temperatures.

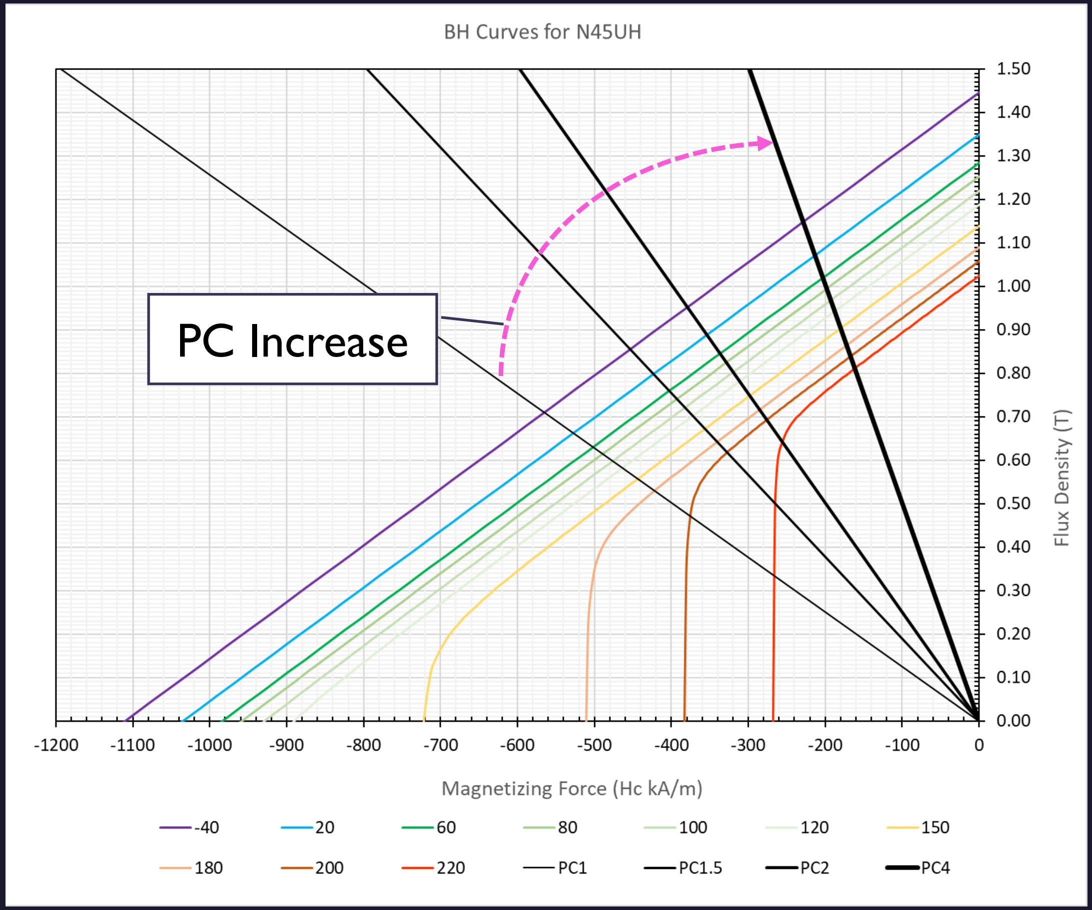
- Reversible Temperature Coefficient for Intrinsic Coercivity Hci (β); β = Δ Hci / Δ T * 100 (%/°C). Usually negative for NdFeB, SmCo, Alnico and positive for Ceramics.



BH-Curve of a Magnet at different Temperatures with Different load-lines (Various permeance Coefficients (PCs))

Thermal Behavior of Permanent Magnets

- The magnet property at different temperatures is derived as parallel lines shown at different temperatures.
- The magnet has its permeance (P_m), whereas the external magnetic circuit is represented as external permeance (P_{ext}) and the ratio of P_{ext}/P_m is defined as Permeance coefficient (*PC*).
- The external circuit is represented as load lines intersecting at 'zero' point of the curve. These load lines change their slop based on their *PCs* shown in figure. Lower *PC* to higher *PC* is shown by arrow.
- Intersection of these load lines with the magnet characteristics defines the magnet operating points.

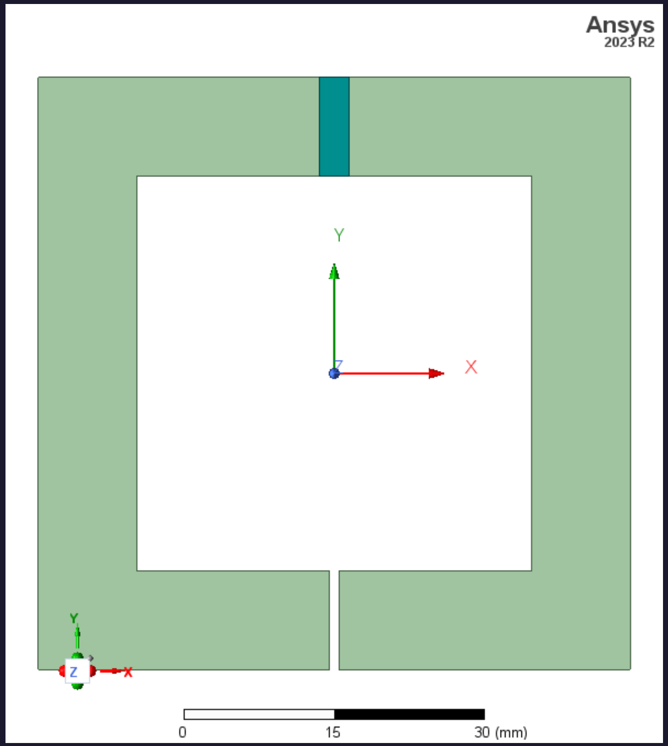


BH-Curve of a Magnet at different Temperatures with Different load-lines (Various permeance Coefficients (PCs))

Difficulty of Solving Thermally Non-linear Problem Using FEA Tools

- At present magnet properties are derived at a specific temperature.
- The *PC*/load line is defined by the solution of the magnetic circuits precisely, however, to analyze PM motor operations precisely by the user, the magnet characteristics at different predicted temperature is selected for the simulation.
- This cause restriction in the parametric analysis at different temperature variations.
- The variations of the temperature is still incorporated by using all the temperature characteristics which are available at discreate temperatures (i.e. -40C, 20C, 60C, 80C, 100C etc. however, this becomes a tedious and lengthy solution.
- This novel method of analysis helps researchers to analyze PM motor at different temperatures using the appropriate parametric set-ups.

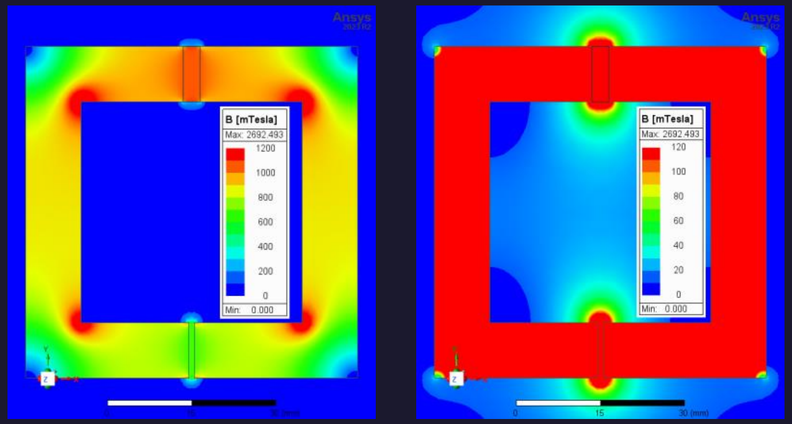
Analytical Model and Implementation in Parametric Solutions



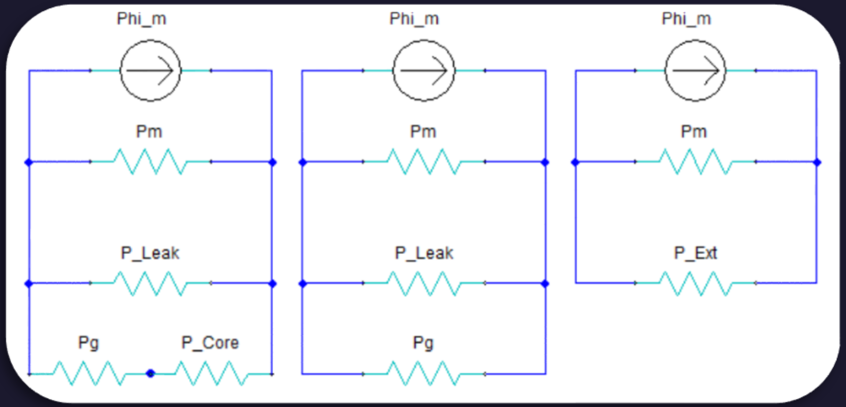
A simple magnetic circuit: (Lm = 3 mm) Core width = 10mm, Core depth = 10 mm, Core length and height = 50 mm)

- A simple magnetic circuit is created to analyze thermal non-linearity model.
- N45UH Material is used for this analysis.
- A 50mmx50mm core geometry having limb width of 10 mm as shown in figure is selected for the analysis.
- Magnet thickness is 3mm and the base airgap is 1mm.
- Magnetic circuit is analyzed at various temperatures to check average flux density in the airgap and within the magnet.
- Assuming the core reluctance is negligible due to its high permeability, majority of the field drop (H) occurs within the airgap.

Analytical Model and Implementation in Parametric Solutions



Flux density showing leakage paths.



Equivalent magnetic circuit.

- Magnet permeance for this circuit is Pm = Assuming the core reluctance is negligible due to its high permeability, majority of the field drop (H) occurs within the airgap.

$$P_m = \frac{\mu_0 \mu_{rec} A_m}{L_m} = \frac{1}{R_m} \qquad P_g = \frac{\mu_0 A_g}{L_g} = \frac{1}{R_g}$$

- The leakage permeance for magnetic circuits is incorporated using different factors like flux concentration factor Cϕ, Karter's coefficient Kc, etc… user can define their leakage factor and flux concentration factor.

- For the selected geometry Kc = 1, Cϕ = 0.62 and PC for 100 C, and 1mm gap is calculated as 4.6.

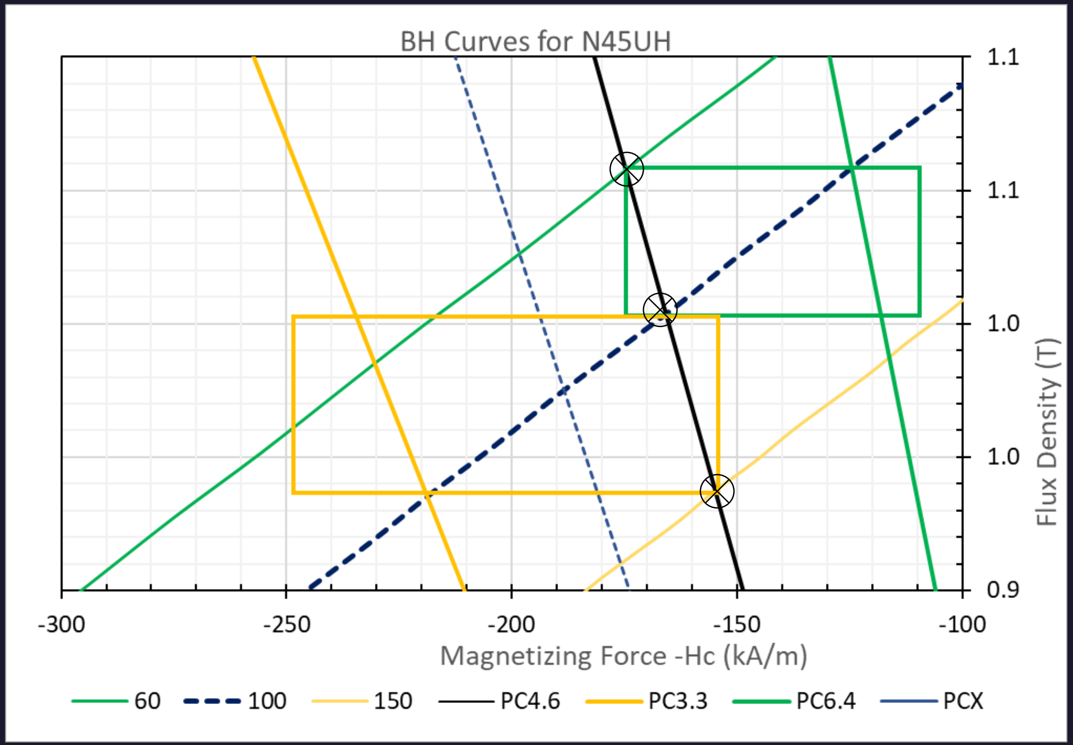
Variation of PC and airgap with temperature

- When Analyzed at 100C, 60C and 150C by replacing the magnet property, the operating points were shifted as shown on a Blacl load line having three intersecting points shown at three temperatures.

- The mean operating temperature is selected to find linear variations above and below the mean temperature. Assuming the magnetic circuit is operated within 20C to 180C.

- The magnet flux density Bm is changing from 1.06T to 0.98T when temperature changes from 60C to 150C.

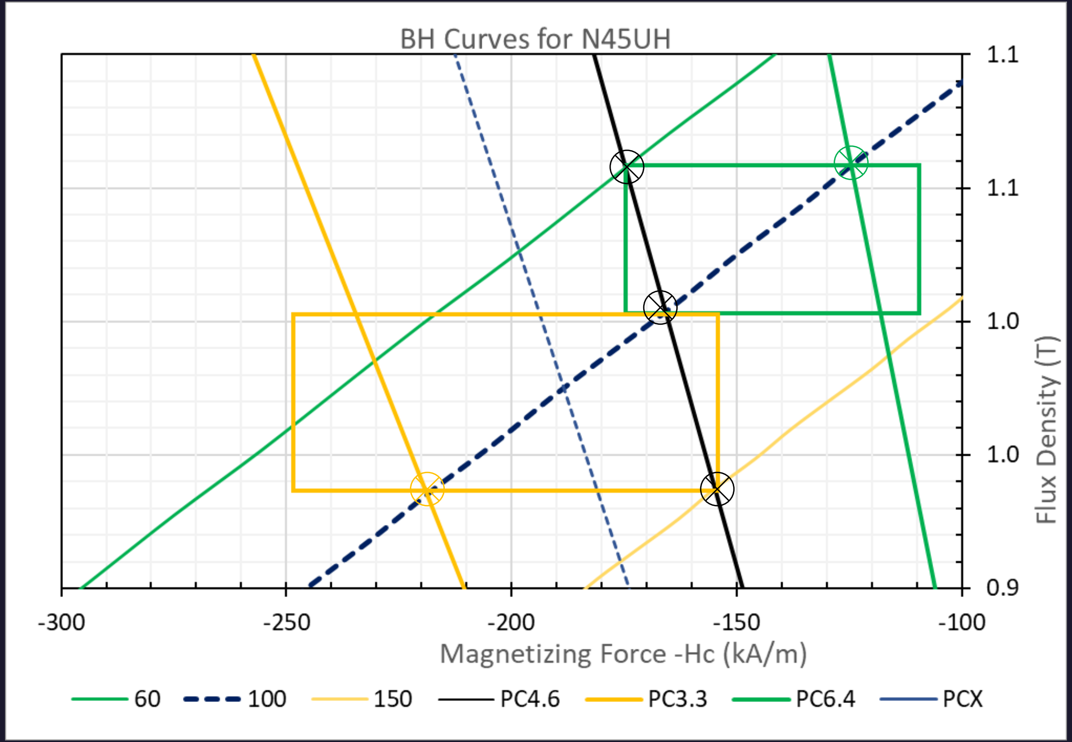
- Here, we did not change load line, therefore the PC remain same for all the three temperatures as shown.



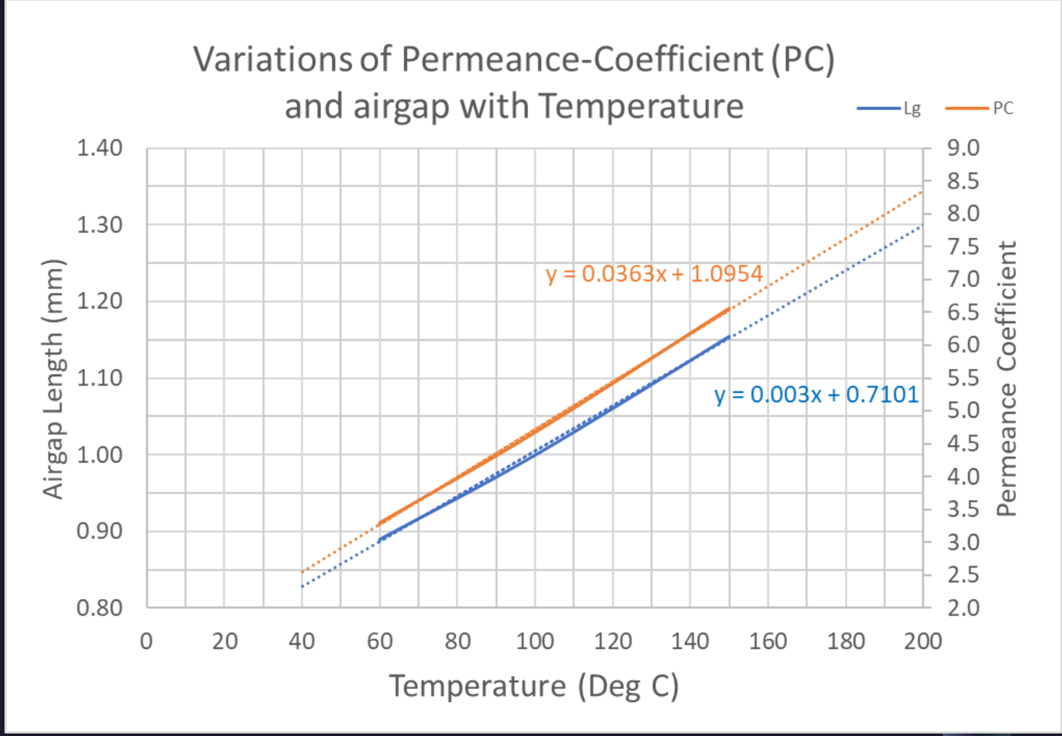
Magnet operations using load-lines at different PCs.

Variation of PC and airgap with temperature

- The value of PC is now changed using the airgap length to achieve similar magnet operating points at the similar permanent magnet characteristics at 100C.
- A linear profile of PC variations and relevant airgap length is established as shown in figure.
- This linear relationship is now used to obtain performance of magnetic circuits.

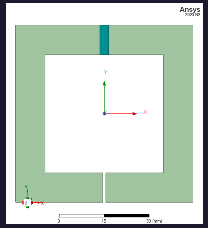


Magnet operations using load-lines at different PCs.

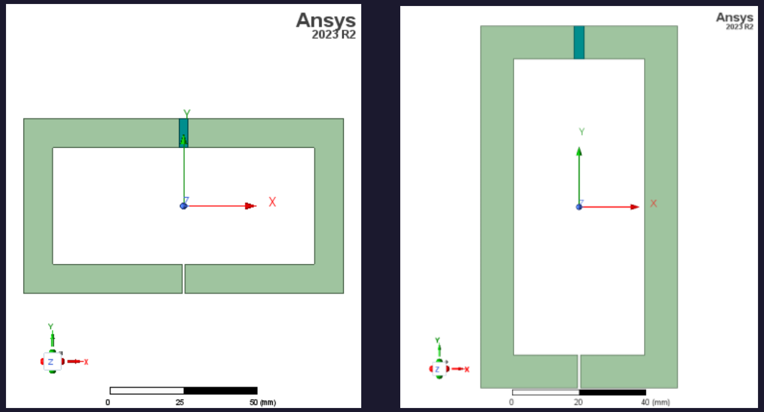


Permeance-coefficient and airgap variation with temperatures.

Conclusions



Base Geometry



Applied geometry variations for different leakage coefficients.

- The magnetic circuit incorporating permanent magnets can be analyzed at various operating temperatures without changing the magnet characteristics.
- It is necessary to find load line variations and establishing relationship between temperatures and airgaps.
- With a smaller airgap variation in the parametric setups, larger temperatures are incorporated in this parametric solution.
- The simulation error depends on how accurately the carter's coefficients, flux concentration factor, leakage factor etc. are derived for the magnetic circuits.

  This is a novel simulation technique; validation is required by users for the effective and efficient results.

Thank You

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