



ELECTROMAGNETIC SYSTEMS AND DEVICES

YEADON ENERGY SYSTEMS, INC.

514 W. Maple St.

Iron River, MI 49935

906-265-7937

yes@yeadoninc.com

www.yeadoninc.com

MODIFICATION OF CLOSED SLOT ROTOR LEAKAGE REACTANCE

HIGH POLE COUNT POLYPHASE INDUCTION MOTORS

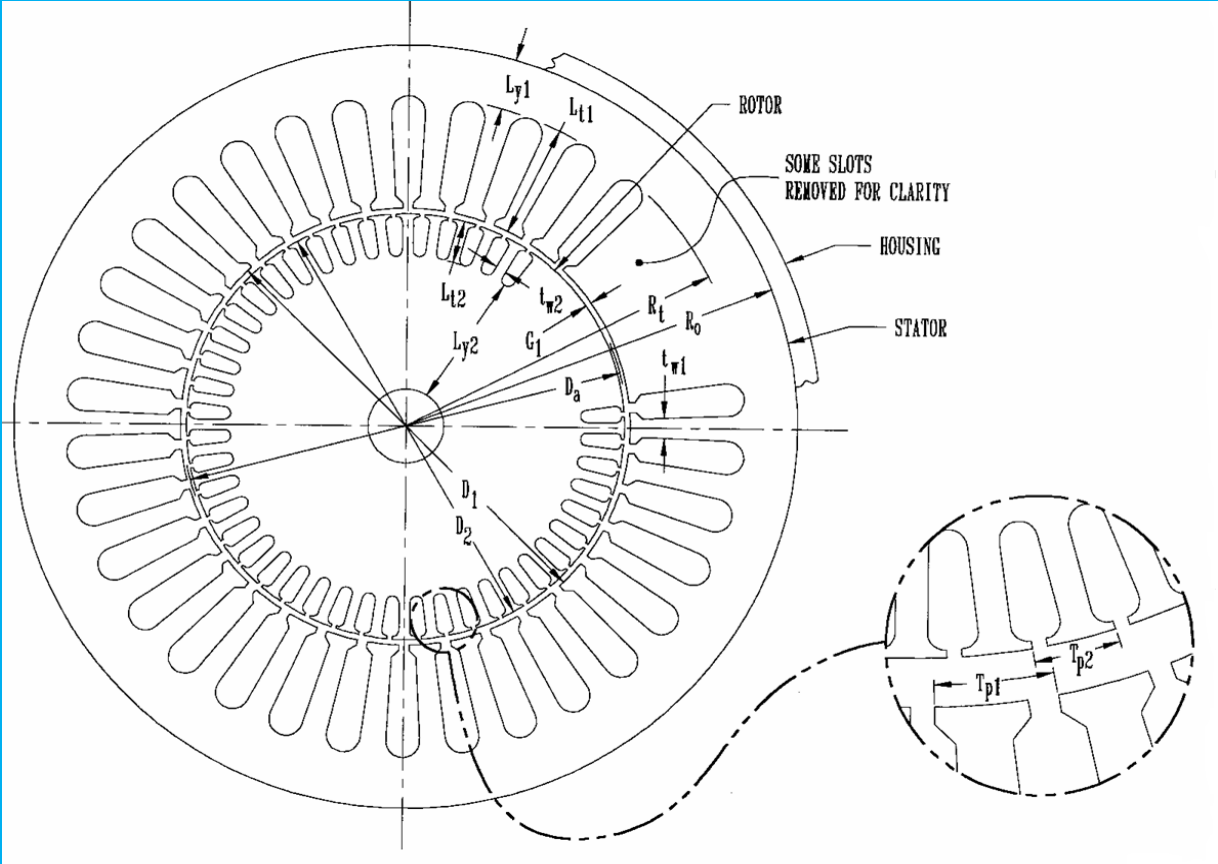
Bradley M. Frustaglio P.E.

and

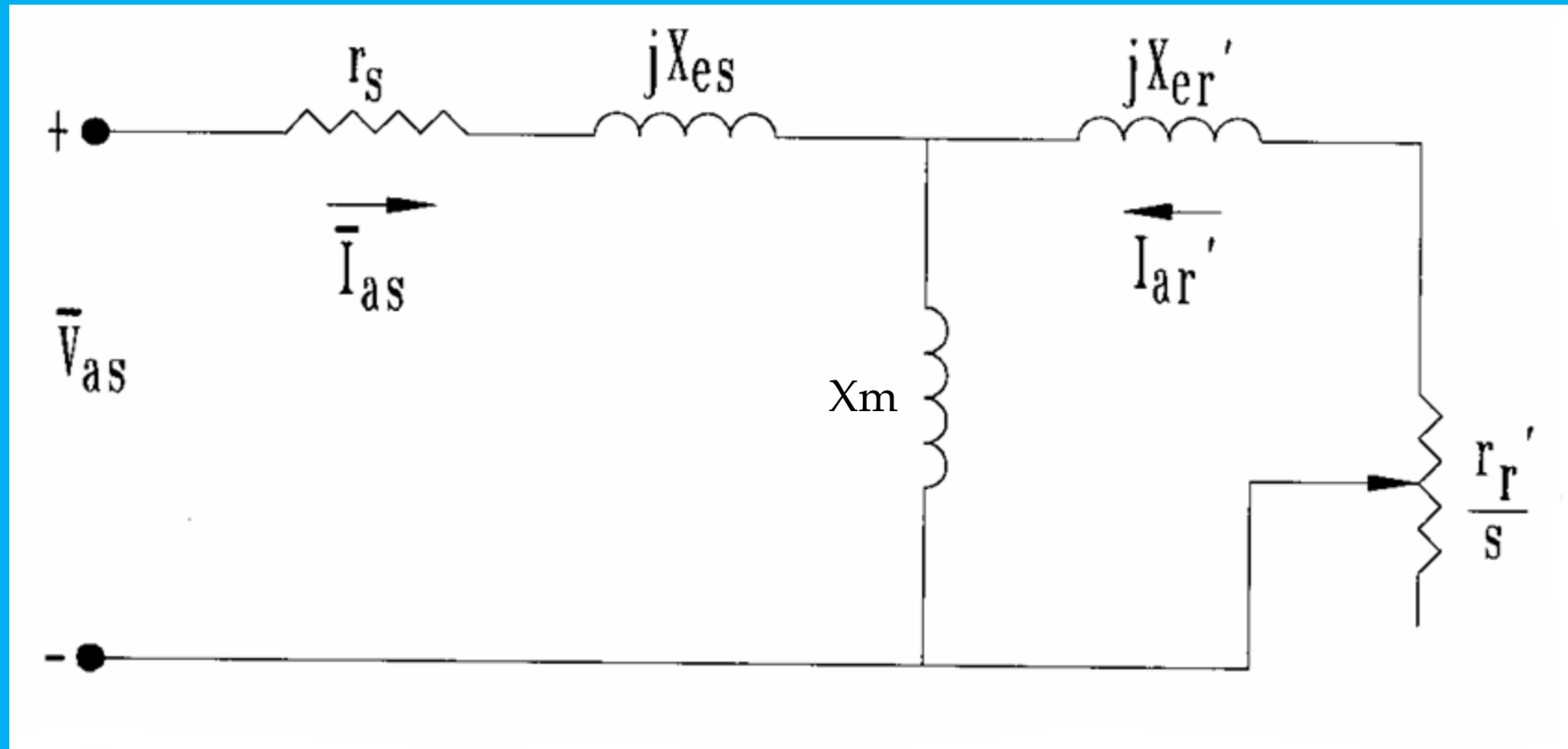
William H. Yeadon P.E.

Yeadon Energy Systems, Inc.

Polyphase Induction Motor



Simplified Equivalent Circuit of One Phase of a Polyphase Motor



Performance Calculation Procedure

- ▣ Calculate the magnetizing current, the total flux, the length and areas of the various flux paths, and the flux densities.
- ▣ From these required ampere turns to produce the flux densities are calculated.
- ▣ The magnetizing current is then calculated from the number of conductors or turns

- ▣ Calculation of the reactive current due to leakage
- ▣ Calculation of performance
- ▣ Calculation of starting conditions

Leakage Reactance

- ▣ Induction motor breakdown torque is primarily determined by the magnitude of leakage reactance.
- ▣ Leakage Reactance - What is it?
 - Leakage Flux - Flux which links only one of the two windings
 - Leakage Reactance - Reactance due to leakage flux

Types of Leakage Reactance

- ▣ Slot Leakage – Rotor and Stator
 - Leakage due to flux crossing the rotor and stator slots
- ▣ Zig-Zag Leakage
 - Leakage Flux crossing the tooth tops
- ▣ End Leakage
 - Leakage flux linking the end turns of the primary and end rings of the secondary
- ▣ Belt Leakage
 - Differential leakage flux due to a difference in distribution of two coupled windings
- ▣ Skew Leakage
 - Differential Leakage flux due to rise in net mutual air gap flux from skew angle

Leakage Permeance

$$P_{xslot} = \left(\frac{3.19w_2m}{S_1} \right) \left[k_1 \left(\frac{S_1}{S_2} \right) k_2 \right]$$

$$P_{xzz} = \left(\frac{1.063w_2m}{S_1G_1} \right) \left[\frac{(T_{f1} + T_{f2})^2}{4(T_{p1} + T_{p2})} \right]$$

$$P_{xend} = \left(\frac{D_1Bm}{S_1P} \right) (1.1 + 0.1p)$$

$$P_{xbelt} = 0.00118m k_m \left(\frac{20p + 0.6}{S_1 + S_2} \right)$$

$$P_{xskew} = 0.324m k_m k_p \left[1 - \frac{\sin(R_s / \theta_p) 90^\circ}{\pi R_s / 2\theta_p} \right]^2$$

$$P_L = P_{xslot} + P_{xzz} + P_{xend} + P_{xbelt} + P_{xskew}$$

$$P_m = 0.324 m k_m \left[\frac{\sin(S_k / \theta_p) 90^\circ}{\pi S_k / 2\theta_p} \right]$$

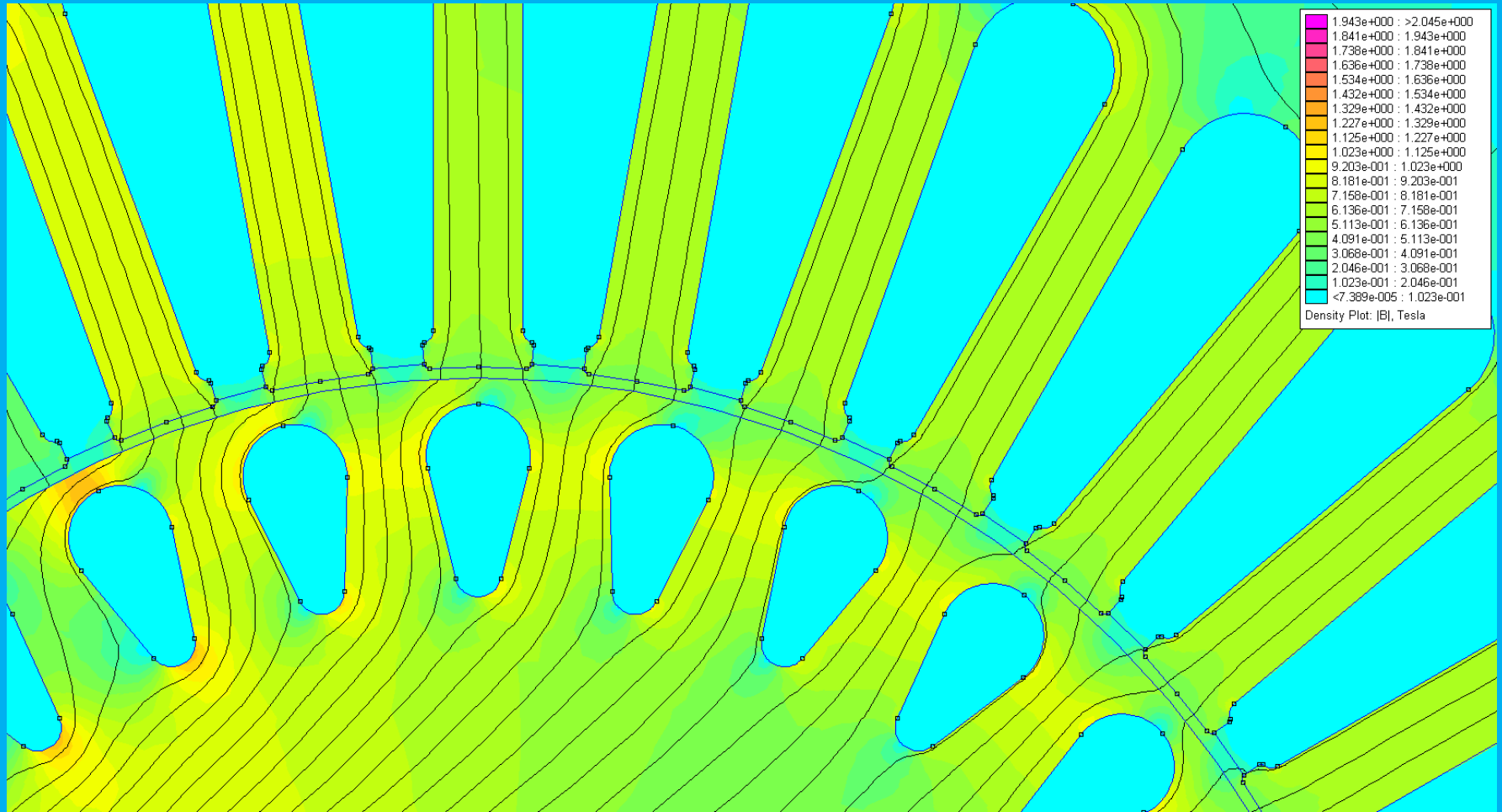
$$P_o = P_m + \frac{P_L}{2}$$

$$X = 2\pi f (Ck_w)^2 10^{-8} P_L \left[\frac{1 + (P_m / P_o)}{2} \right]$$

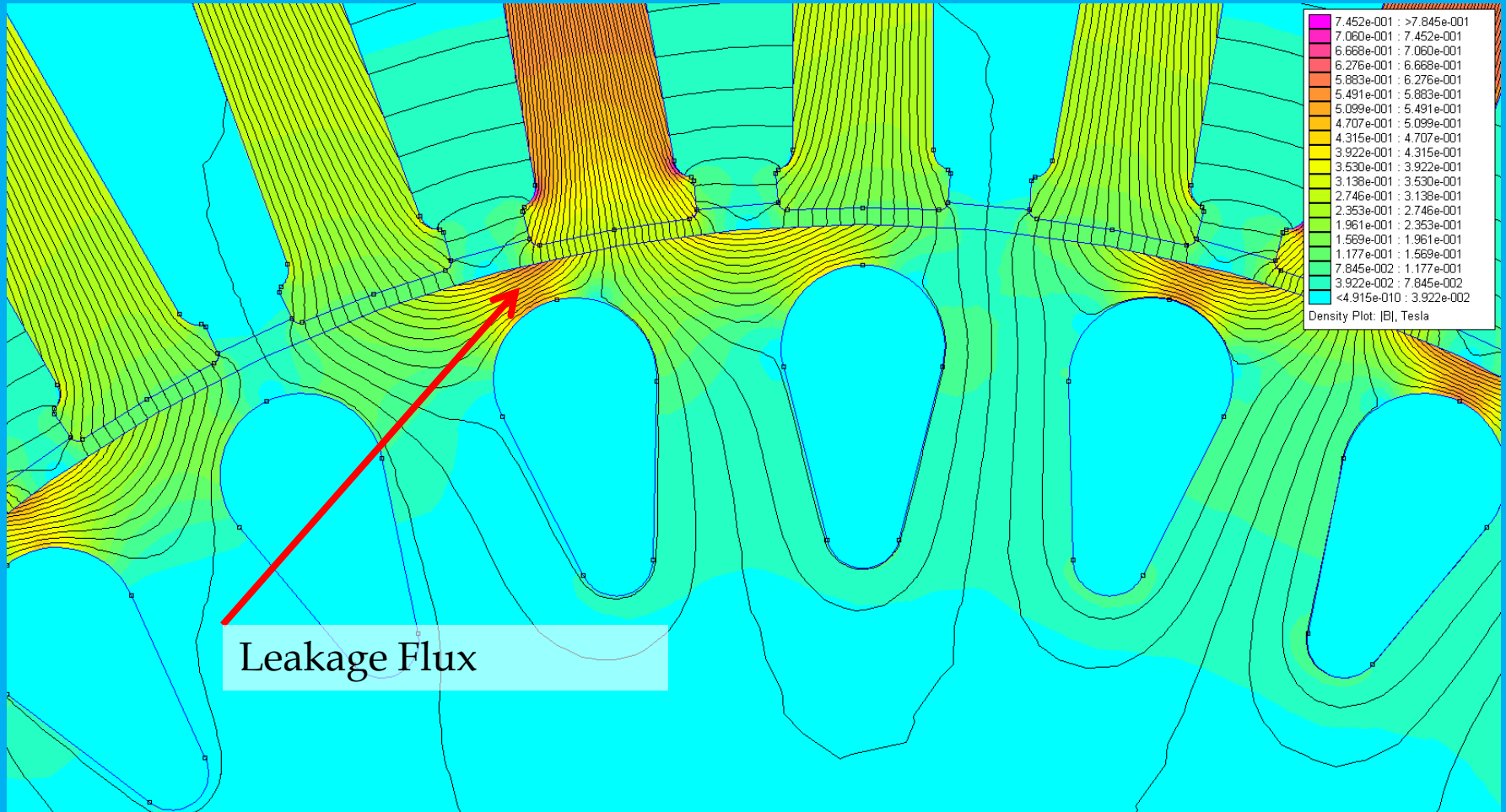
Leakage Problem Defined

- ▣ Low Pole Count vs. High Pole Count Designs
- ▣ Flux Paths
 - Same number of Stator and Rotor Slots
 - Different Pole Counts

2 Pole Flux Path



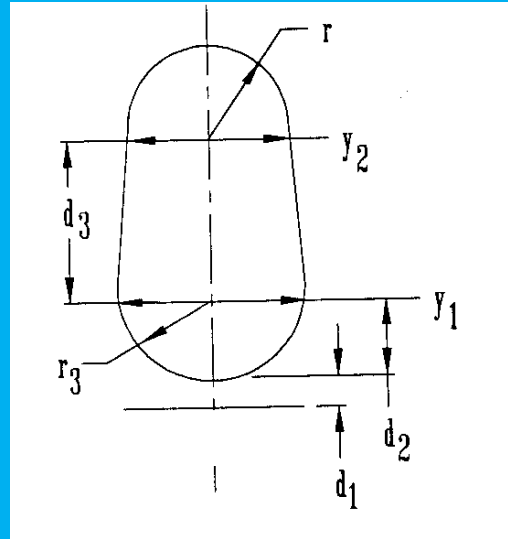
24 Pole Flux Path



Rotor Slot Leakage

- ▣ Modify rotor slot leakage to better calculate this leakage path in high pole count designs with closed slot rotors

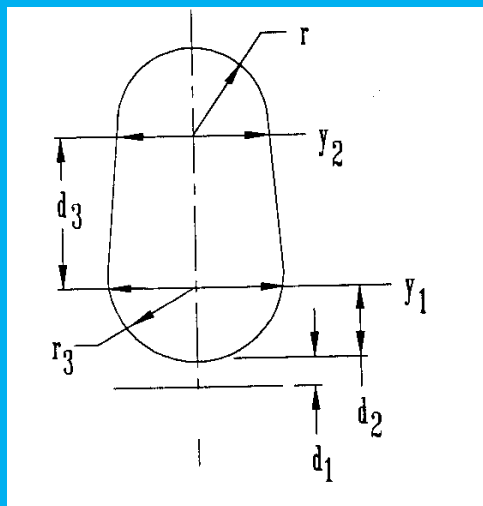
Round Bottom Closed Slot



Existing Closed Slot Constant Formula

$$k_2 = \frac{0.284 - 0.143(y_1 / y_2) + (d_3 / y_1)}{2.87(y_1 / y_2) + 0.96}$$

Round Bottom Closed Slot



Modified Closed Slot Constant Formula

Function of

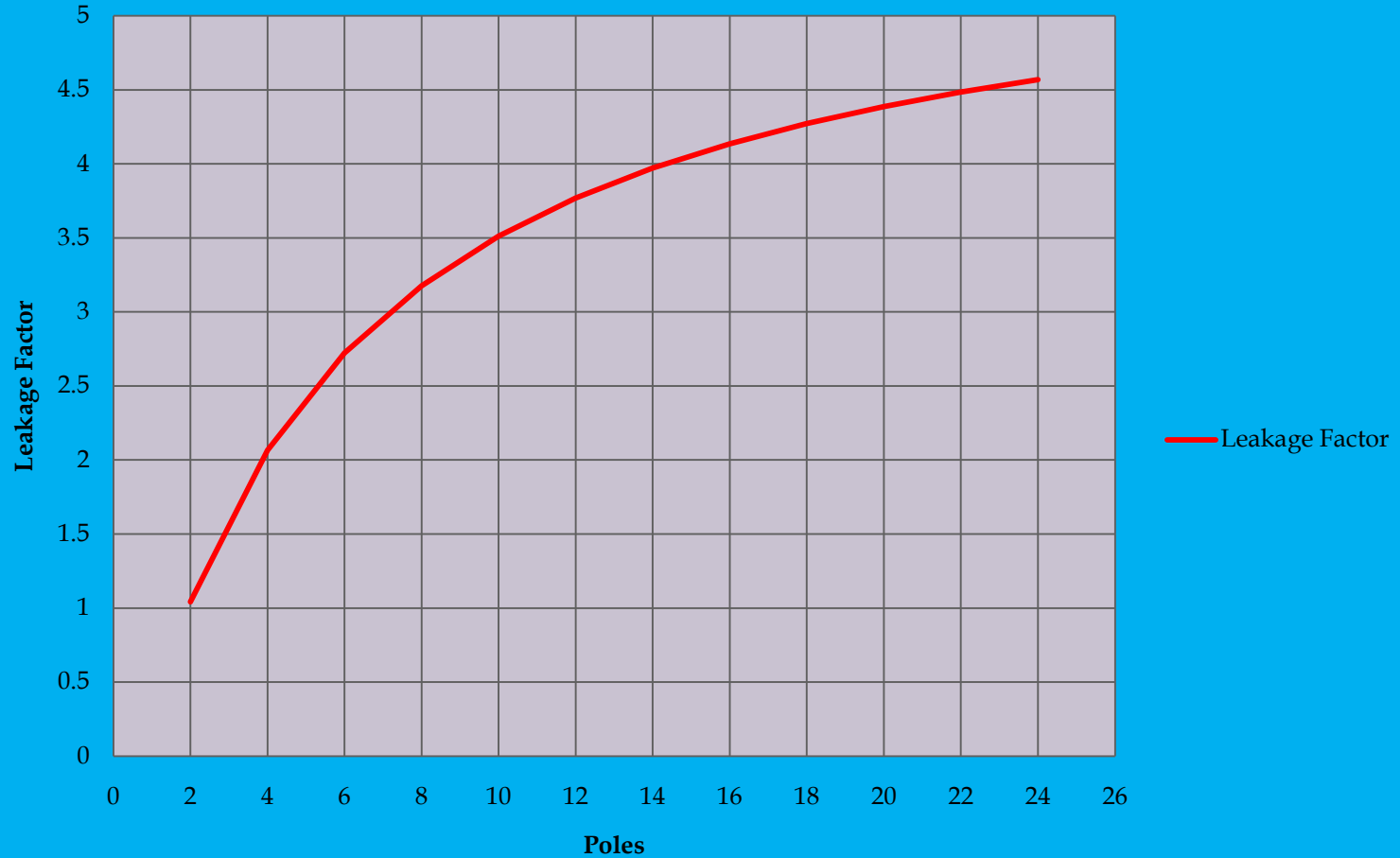
- Slot Bridge Dimension d_1
- Slot Width Dimension y_1
- Average number of slots per pole N_{sp}

$$N_{sp} = \frac{S_1 + S_2}{2P} \quad M = \frac{.04}{\left(\frac{d_1}{y_1}\right) N_{sp}}$$

$$k_2 = \frac{0.284 - 0.143(y_1 / y_2) + (d_3 / y_1)}{2.87(y_1 / y_2) + 0.96} \left(\frac{6.49}{1 + M} - .78 \right)$$

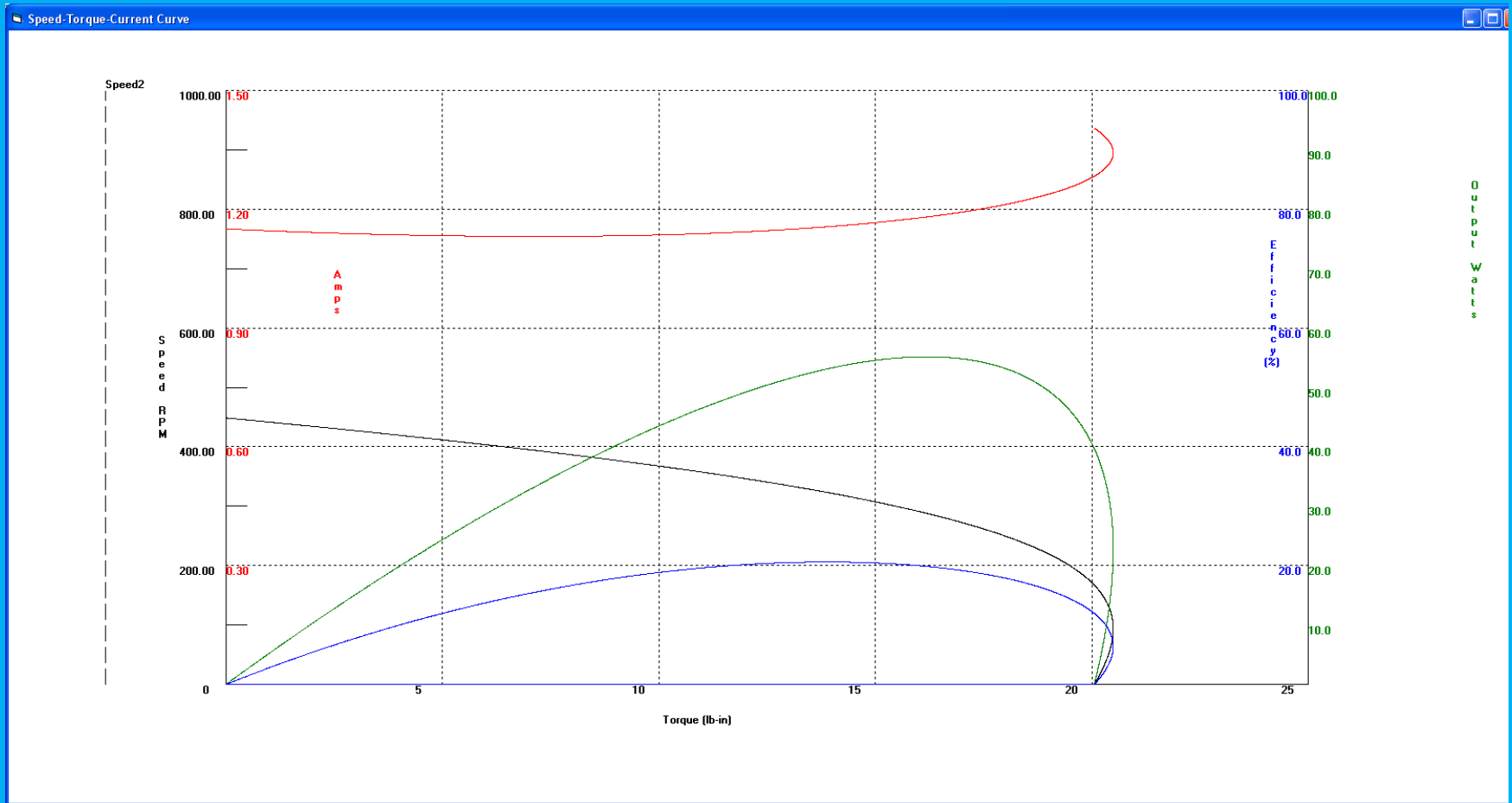
Closed Slot Leakage Factor

Closed Slot Leakage Factor vs. Pole Count



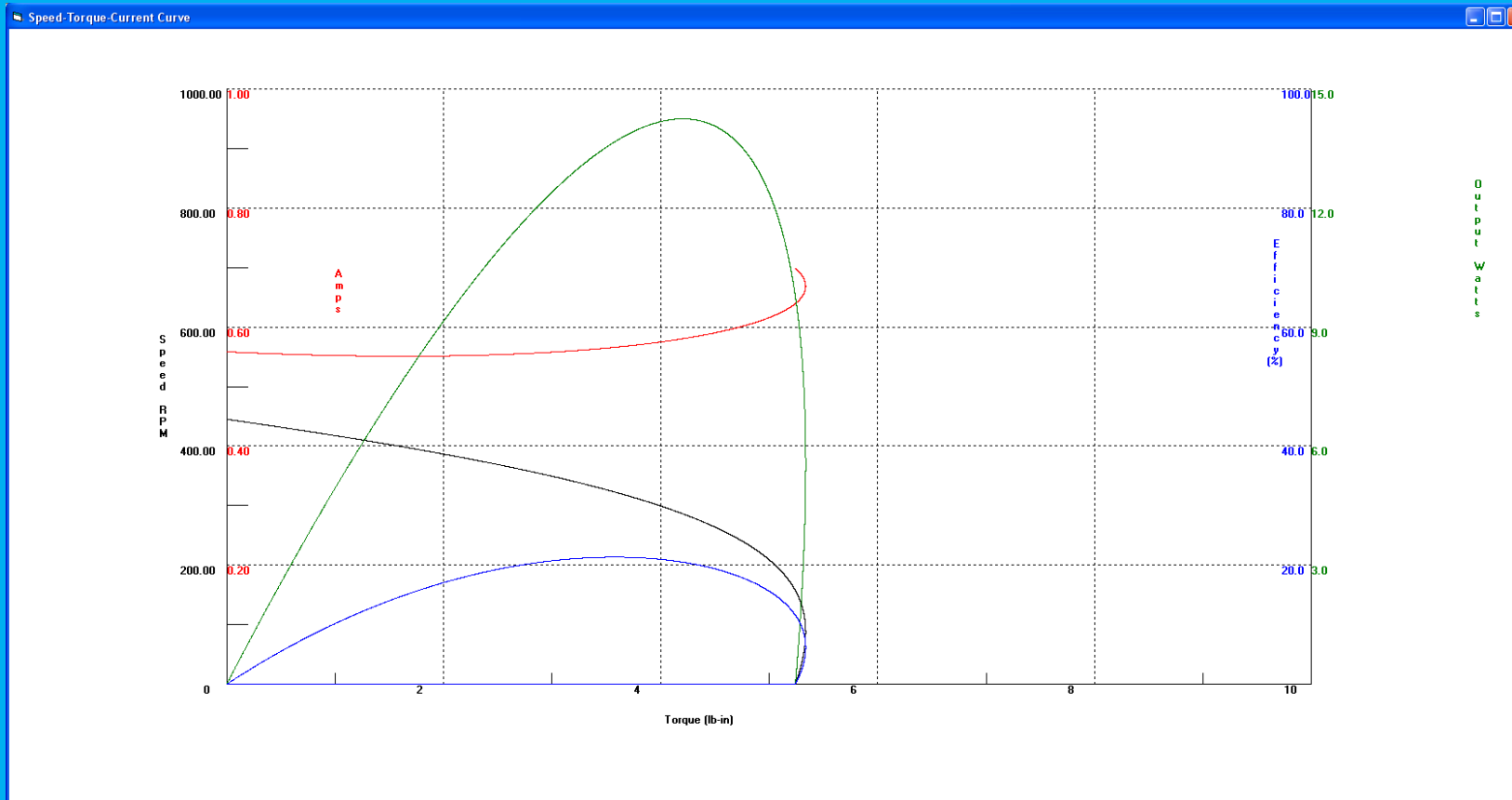
16 Pole Simulated Performance Curve With Original Slot Leakage Formula

Breakdown Torque - 20.49 in-lbs



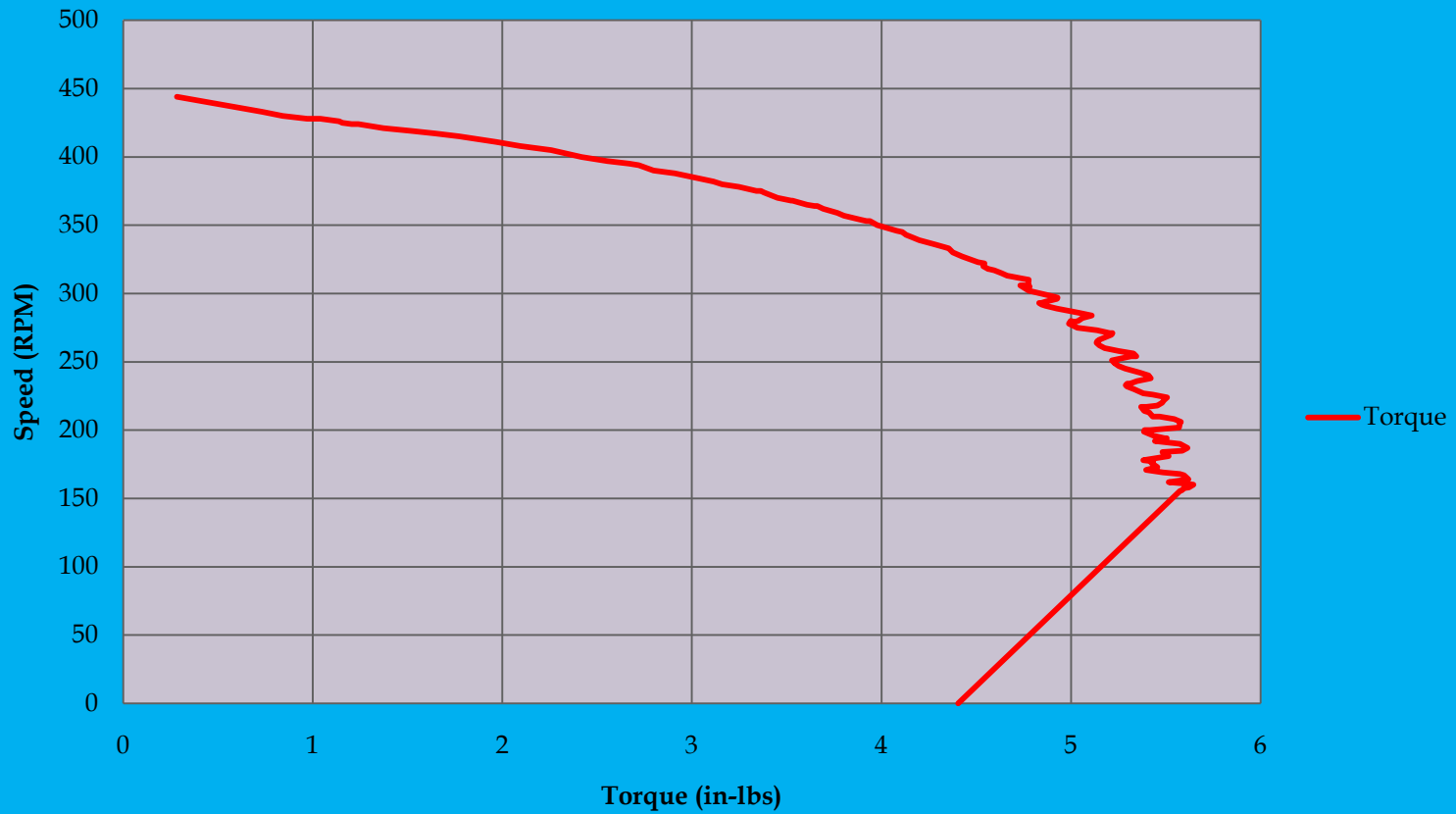
16 Pole Simulated Performance Curve With Modified Slot Leakage Formula

Breakdown Torque - 5.34 in-lbs



Dynamometer Test Data 16 Pole Design

16 Pole Polyphase Speed - Torque



Summary

- ▣ Closed Slot Rotor Leakage
 - Dependant on slot bridge dimension
 - Becomes an issue on high pole count designs
- ▣ Developed empirical factor applied to rotor slot leakage to better predict the performance on high pole count closed slot rotors

THANK YOU