Kruse Motion Control Summary

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June 12, 2002

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Summary:

Kruse Control is a patented, High Performance motion control approach for Stepper and brushless DC motors (A 2-phase Stepper Motor with 1.8°/step, is a 50 pole brushless DC motor). Low cost is realized when the encoder is eliminated by using a TI 24X DSP to estimate the motor shaft position from integration of quadrature back emf voltages, and compute a PID compensator. Hardware consists of one H-bridge/phase and some op-amps/analog switches to integrate the sense windings.

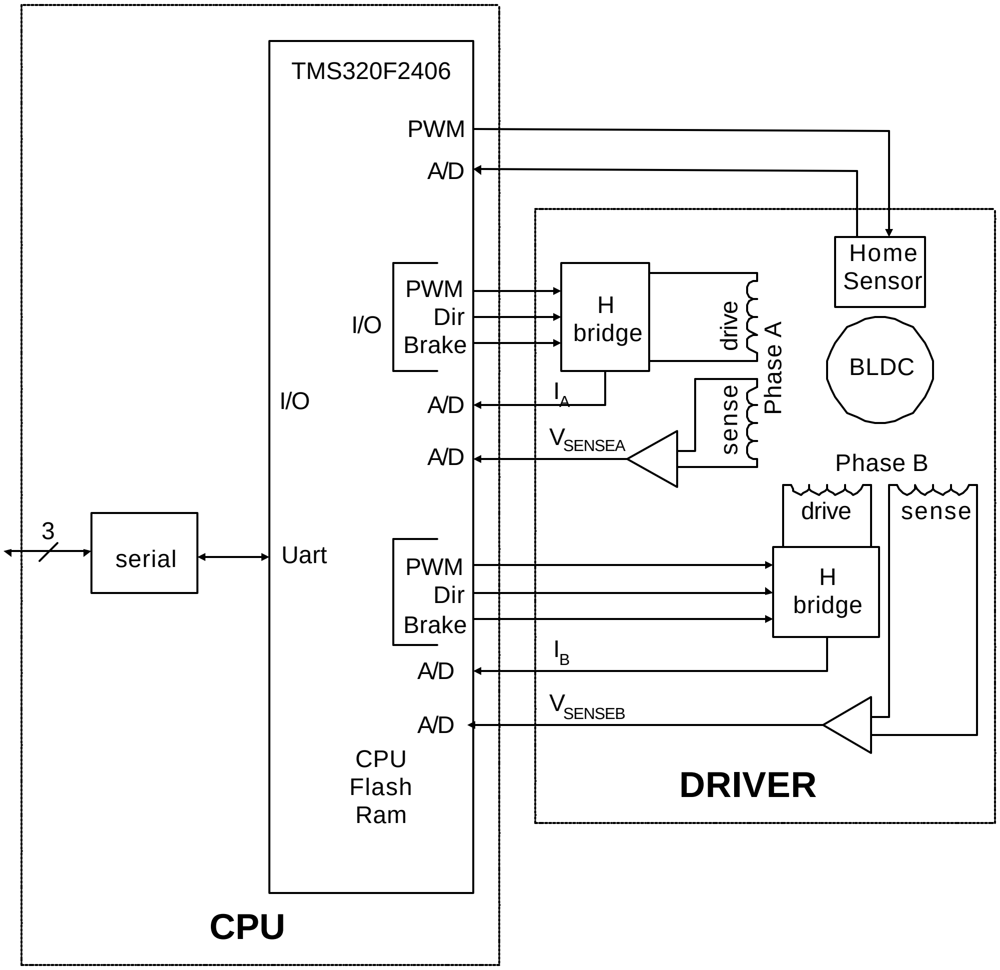

Figure 1, Kruse Control Hardware Block Diagram

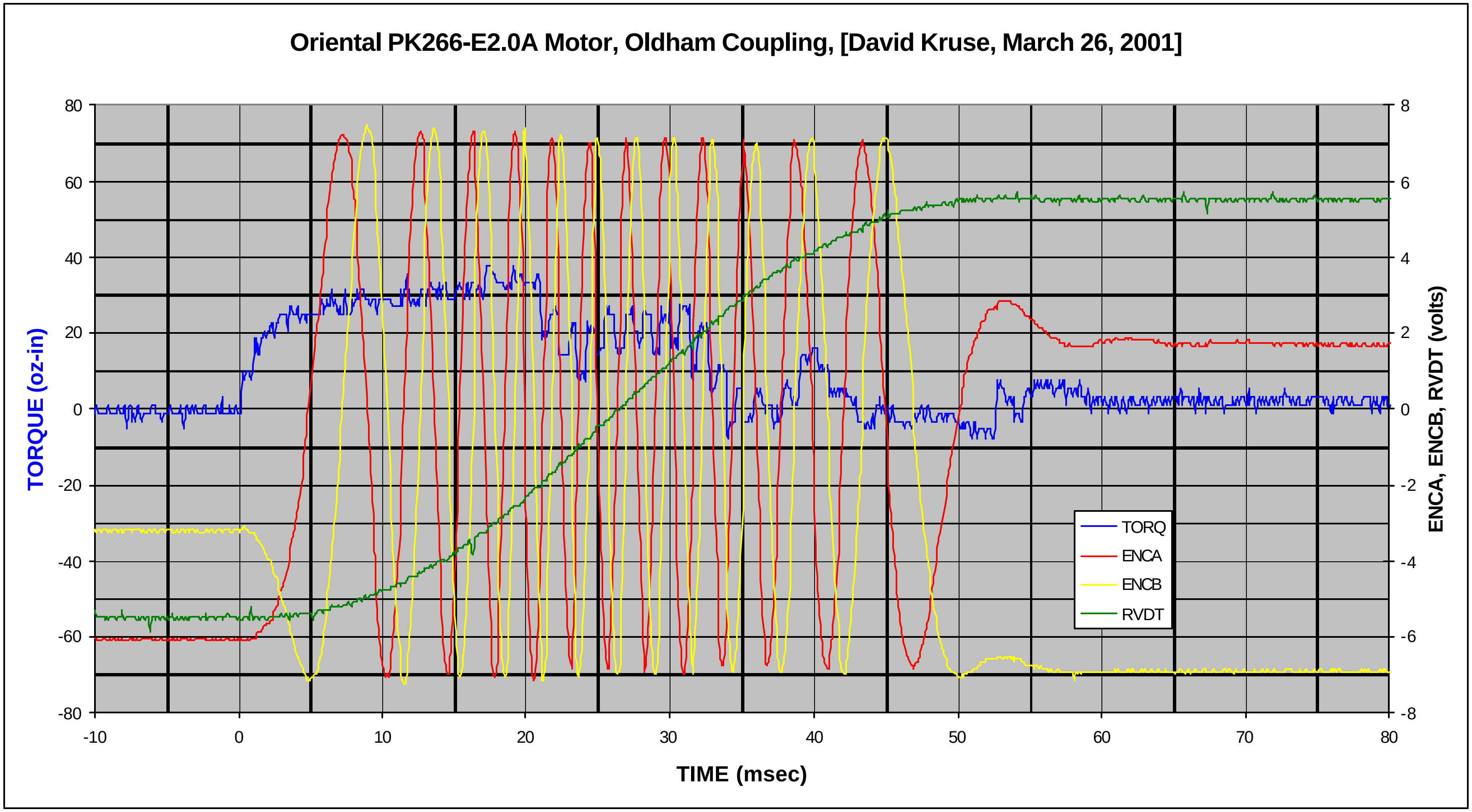

Figure 2, Kruse Control System Signals

180.0° move Performance Comparision between open-loop stepping and Kruse Control.

Parameter	Open Loop	Kruse Control
Time (msec)	100	50
Power Consumption	Lossy	60% lower than Open Loop
Torque		
Low Speed	Reasonable	Excellent
High Speed	Poor	Excellent
Mechanical Resonance	Potential problems	Compensated
Feedback	None	10,000 count/rev incremental encoder

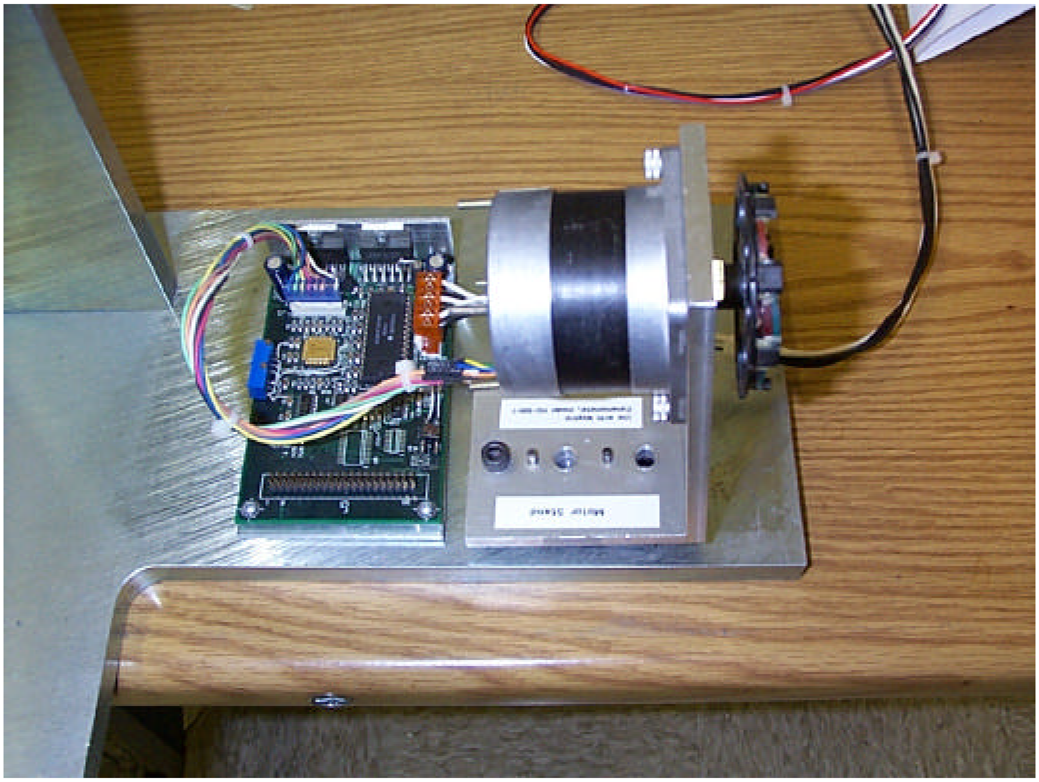

Figure 2, Kruse Motion Control 180.0° Filter Wheel Demo

For questions please call:

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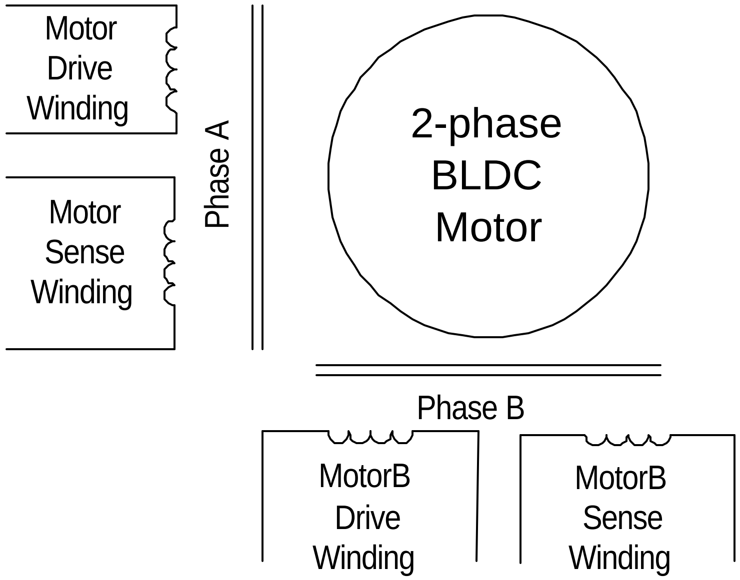
Appendix A: Kruse Control Theory

A two phase brushless DC motor contains two electromagnetic stator phases (A and B) which, when excited by an electrical current, each produce a torque due to magnetic attraction to a segmented permanent magnet rotor. The total torque produced is the algebraic sum of the phase torques. The torque produced by each phase is the product of its current (i_A or i_B), and its torque sensitivity k_T.



Ideally, the torque sensitivity of each phase is a sinusoidal function of the rotor position relative to the stator (θ_R), and the phase of the relationship between the two phases is 90°. Expressed mathematically:

$$T = T_A + T_B \qquad (1.1)$$

$$T_A = i_A * k_T * \sin(n\theta_R)$$

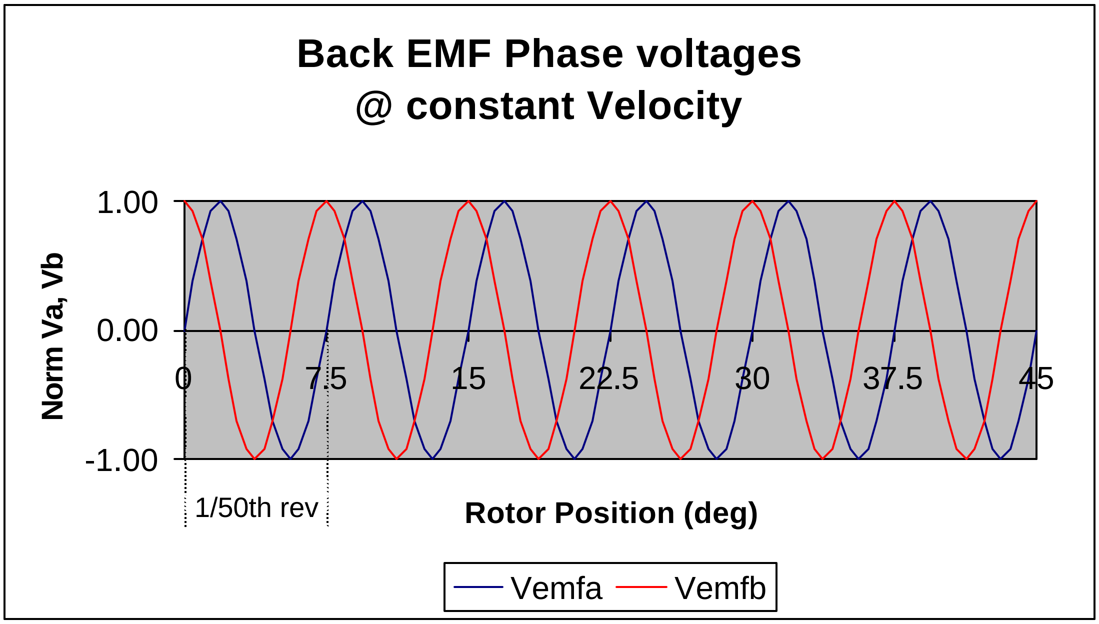
$$T_B = i_B * k_T * \cos(n\theta_R) \qquad (1.2)$$

$$\theta_R = \theta_0 + \varpi t$$

n = number of rotor permanent magnet pole pairs ($n=50$ for 1.8° motor)

ϖ = rotor angular velocity

t = time



The electromagnetic phases, constructed of coils of conductors about the stator poles through which magnetic flux linking rotor with stator flows, possess characteristics of distributed resistance, inductance and voltage (EMF) generator in series. Expressed mathematically:

$$V_A=R*i_A+L*di_A/dt+V_{EMFA}$$

$$V_B=R*i_B+L*di_B/dt+V_{EMFB} \qquad (1.3)$$

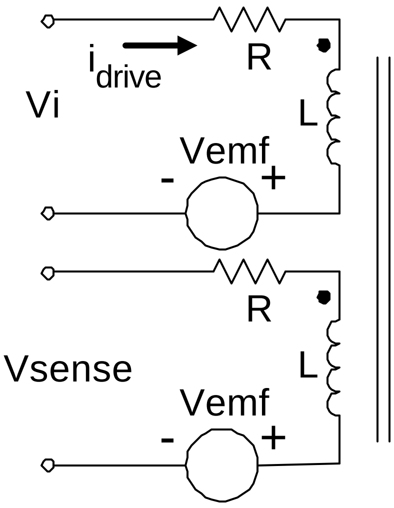
Where the electromotive force (EMF) induced in each phase is a rotor position dependent sinusoid which is in phase with its respective torque sensitivity and whose magnitude is proportional to the EMF constant of proportionality K_E and rotor angular velocity ϖ.

$$V_{EMFA}=\varpi*k_E*\sin(n*\theta_R)$$

$$V_{EMFB}=\varpi k_E\cos(n\theta_R) \qquad (1.4)$$

Motor Phase Equivalent Circuit:

Applying Kerkioff's voltage laws:



$$V_I = I*R+L*di/dt +V_{EMF}$$

$$V_{SENSE} = L*di_{DRIVE}/dt +V_{EMF}$$

Position Detection:

The position control algorithm is shown in the control flow diagram below (figure 2). The position of the rotor θ_R (relative to the stator), is accurately represented by the integrals of the EMFs (1.4) induced in the two phases of the motor. Each phase of the motor is equipped with a secondary winding (about the same stator poles) to sense these EMFs. As they are coupled to their respective drive windings via mututal inductance, the voltages developed across those inductances as a result of the excitation currents is additive to the EMFs induced in the sense windings. That is, if the number of turns in the sense windings is equal to those of the drive windings, the voltages developed across the sense windings are expressed as:

$$V_{ASENSE} = L*di_A/dt+V_{EMFA} = L*di_A/dt+k_E*\varpi*\sin(n\theta_R)$$

$$V_{BSENSE} = L*di_B/dt+V_{EMFB} = L*di_B/dt+k_E*\varpi*\cos(n\theta_R) \tag{1.7}$$

Which are independent of the voltages developed across the drive winding resistances (iR) and thus, substantially independent of the temperature. The output of each sense winding is integrated and summed with a voltage proportional to the excitation current and its drive winding.

$$V_{APOS} = k_2*i_A+ k_1*\Sigma\ V_{ASENSE} = k_2*i_A + k_1*(Li_A-k_E/n)*(\cos(n*\theta_R))$$

$$V_{BPOS} = k_2*i_B+ k_1*\Sigma\ V_{BSENSE} = k_2*i_B + k_1*(Li_B-k_E/n)*(\sin(n*\theta_R))$$

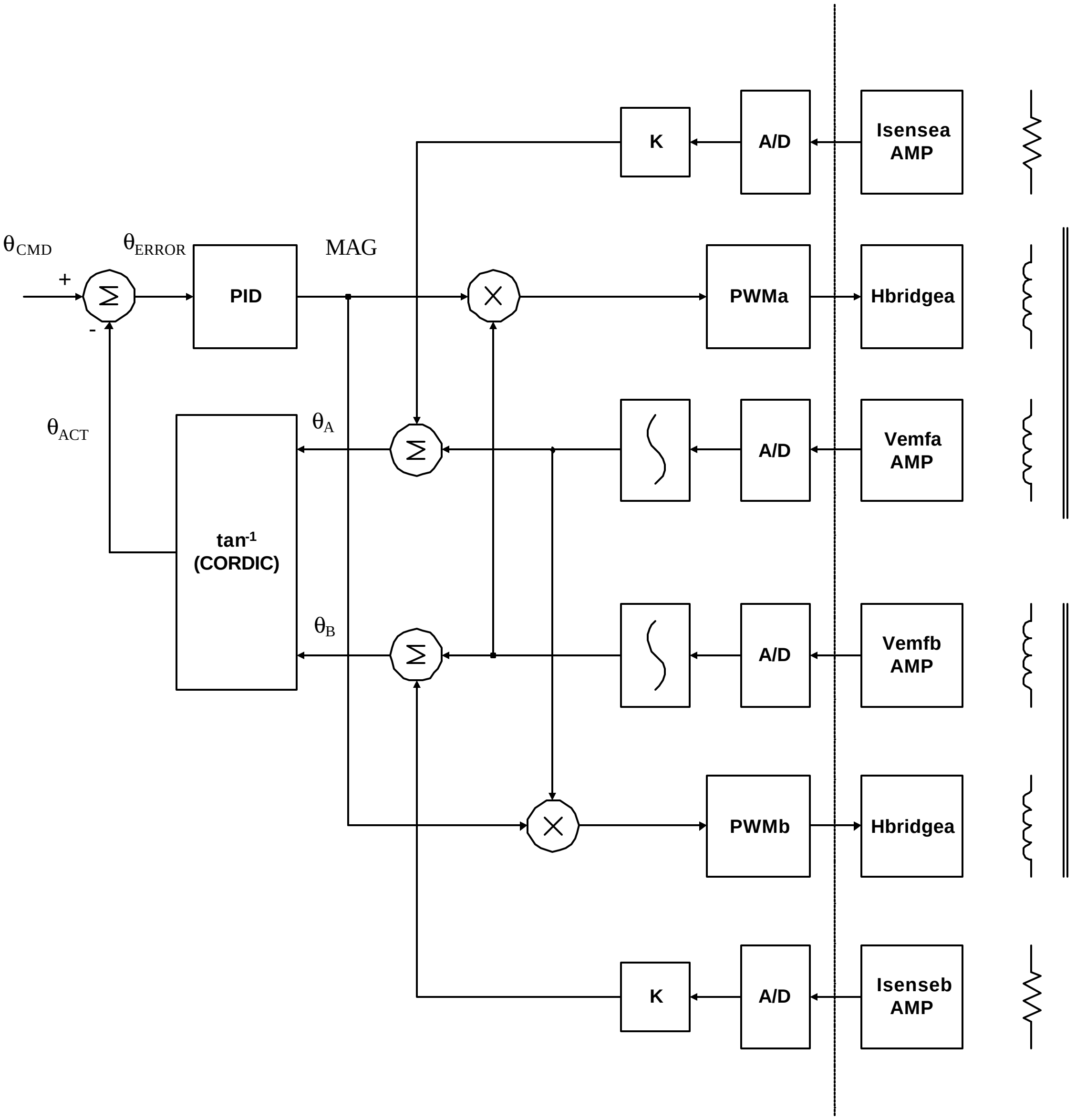


figure 2, Control Flow Diagram

Control Methodology:

If each phase of the motor is excited with a current proportional to the product of the integral of the EMF of the other phase and a control signal (MAG)

$$i_A = k_V{*}_{MAG} \Sigma\, k_E{*}\cos(n{*}\varpi t) = V_{MAG}{*}k{*}k_E/n\, {*}\sin(n\varpi t) = I{*}\sin(n{*}\varpi t)$$

$$i_B = k_V{*}_{MAG} \Sigma\, k_E{*}\sin(n{*}\varpi t) = V_{MAG}{*}k{*}k_E/n\, {*}\cos(n\varpi t) = I{*}\cos(n{*}\varpi t) \qquad (1.5)$$

then a torque produced

$$T= (V_{MAG}{*}k{*}k_E{*}k_T/n){*}(\sin^2(n{*}\varpi t) + \cos^2(n{*}\varpi t))= V_{MAG}{*}k{*}k_E/n = k_T{*}I$$

Which is:

1. linearly related to control signal MAG
2. Is independent of rotor position and velocity
3. Maximizes motor efficiency
4. Minimizes torque ripple and audible noise

Furthermore, the motor is effectively self-commutating by virtue of its own motor⇔generator characteristics. Performance of brushless DC motors is intimately tied to the commutation of current in motor windings.