Permanent Magnet Vernier Motors

T.A. Lipo

Some History

C.H. Lee, “Vernier Motor and Its Design”, IEEE Trans. On Power Apparatus and Systems, Vol. 82, No. 66, 1960, pp 343-349.

A. Ishizaki, T. Tanaka, K. Takahashi and S. Nishikata, “Theory and Optimum Design of PM Vernier Motor”, Proc. of IEEE ICEMD’95, 1995, pp. 208-212.

A. Toba and T.A. Lipo, “Novel Dual-Excitation Permanent Magnet Vernier Machine”, Conference Record, 34th IAS Annual Meeting, 1999, pp. 2539-2544.

Conventional PM Motor

p : winding pole pairs

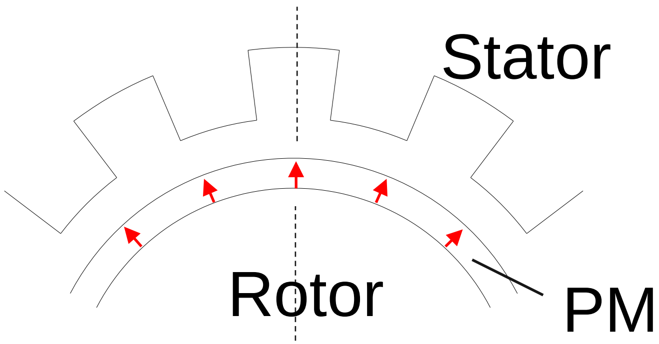
q: slots/pole/phase

Z_s : slots $\left(=6pq\right)$

Z_r : rotor pole pairs

Gap Permeance

$$P\left(\theta\right)=P_0-P_1\cos\left(Z_s\theta\right)$$



$Z_r = p$

MMF of PM

$$F_{PM}\left(\theta\right)\approx F_{PM1}\cos\left(Z_r\left(\theta-\theta_m\right)\right)$$

$$B\left(\theta\right)=P\left(\theta\right)F_{PM}\left(\theta\right)$$

Conventional PM Motor

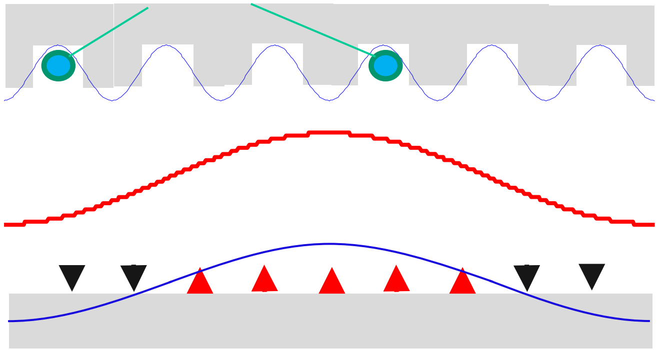
p : winding pole pairs

q: slots/pole/phase

Z_s : slots $\left(=6pq\right)$

Z_r : rotor pole pairs

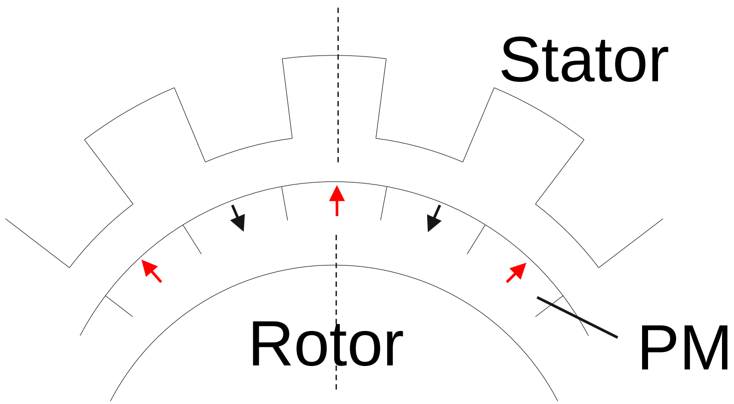
Stator conductors



$$E_{conv} = \frac{k_{1q} N_{ph} D_i l_c \omega_m}{\sqrt{2}} \left(B_{g0}\right)$$

$$= k_E \omega_m B_{PM0}$$

Vernier Motor



Z_r=p(6q-1) :Zr-Zs=-p

Gap Permeance

$$P(\theta) = P_0 - P_1 \cos(Z_s \theta)$$

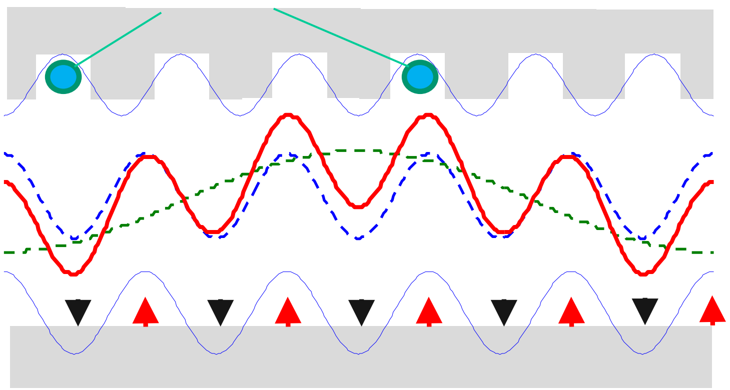
MMF of PM

$$F_{PM}(\theta) \approx F_{PM1} \cos\left(Z_r(\theta - \theta_m)\right)$$

$$B_{g0} = F_{1g,m} P_0$$

$$\frac{B_{g1}}{2} = F_{1g,m} P_1$$

Vernier Motor EMF



Gap Permeance

$$P(\theta) = P_0 - P_1 \cos(Z_s \theta)$$

MMF of PM

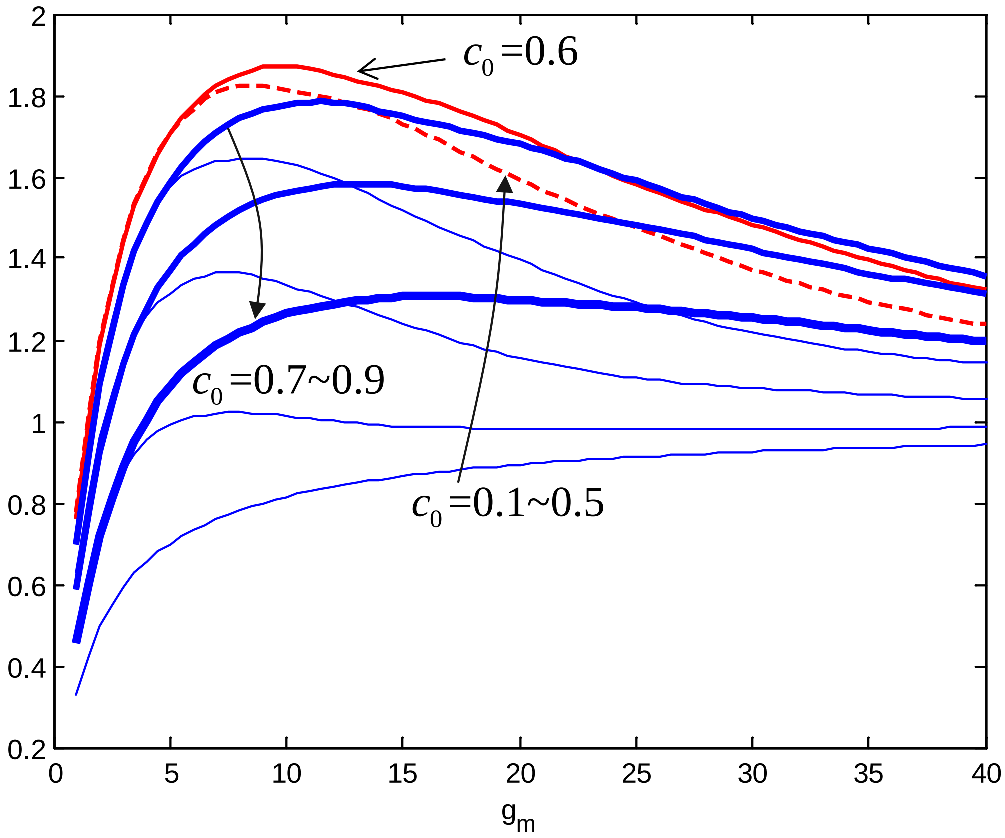
$$F_{PM}(\theta) \approx F_{PM1} \cos(Z_r(\theta - \theta_m))$$

$$E_{ver} = \frac{k_{1q} N_{ph} D_i l_c \omega_m}{\sqrt{2}} \left(B_{PM0} - \frac{Z_r}{2(Z_r - Z_s)} B_{PM1} \right)$$

$$= k_E \omega_m \left(B_{PM0} + \frac{(6q-1)}{2} B_{PM1} \right)$$

Effect of Slot Opening on EMF

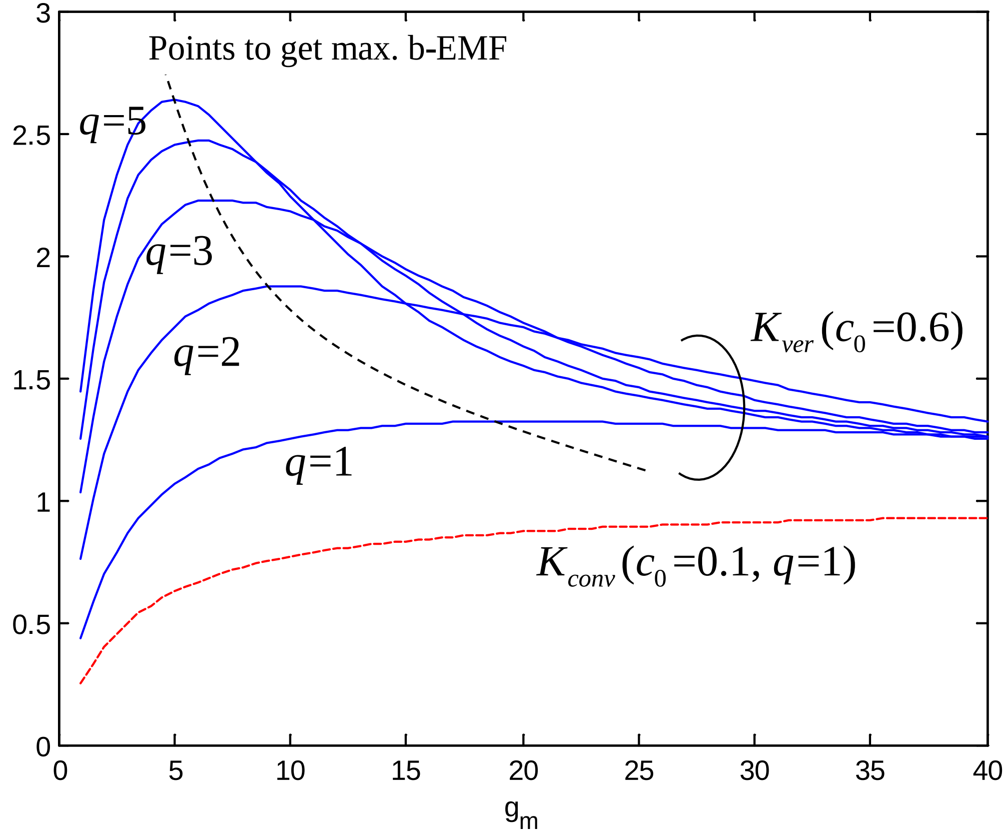
EMF Factor



c_0 = slot width/slot pitch

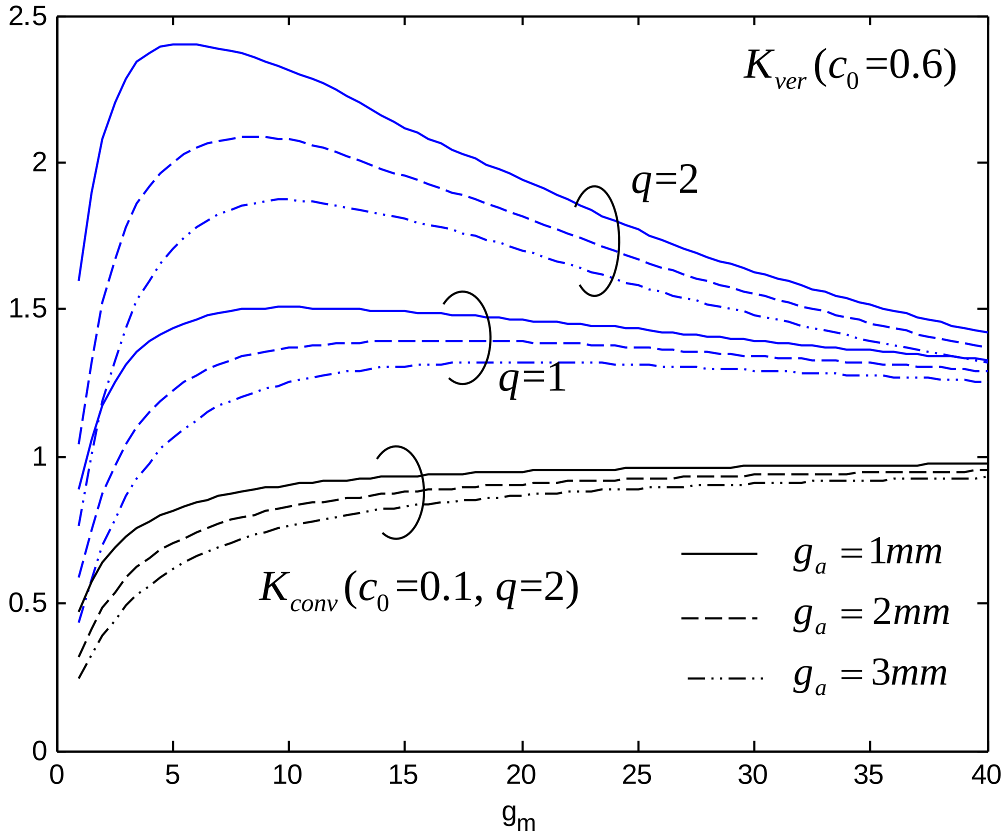
Effect of q = slots/pole/phase on EMF

EMF Factor

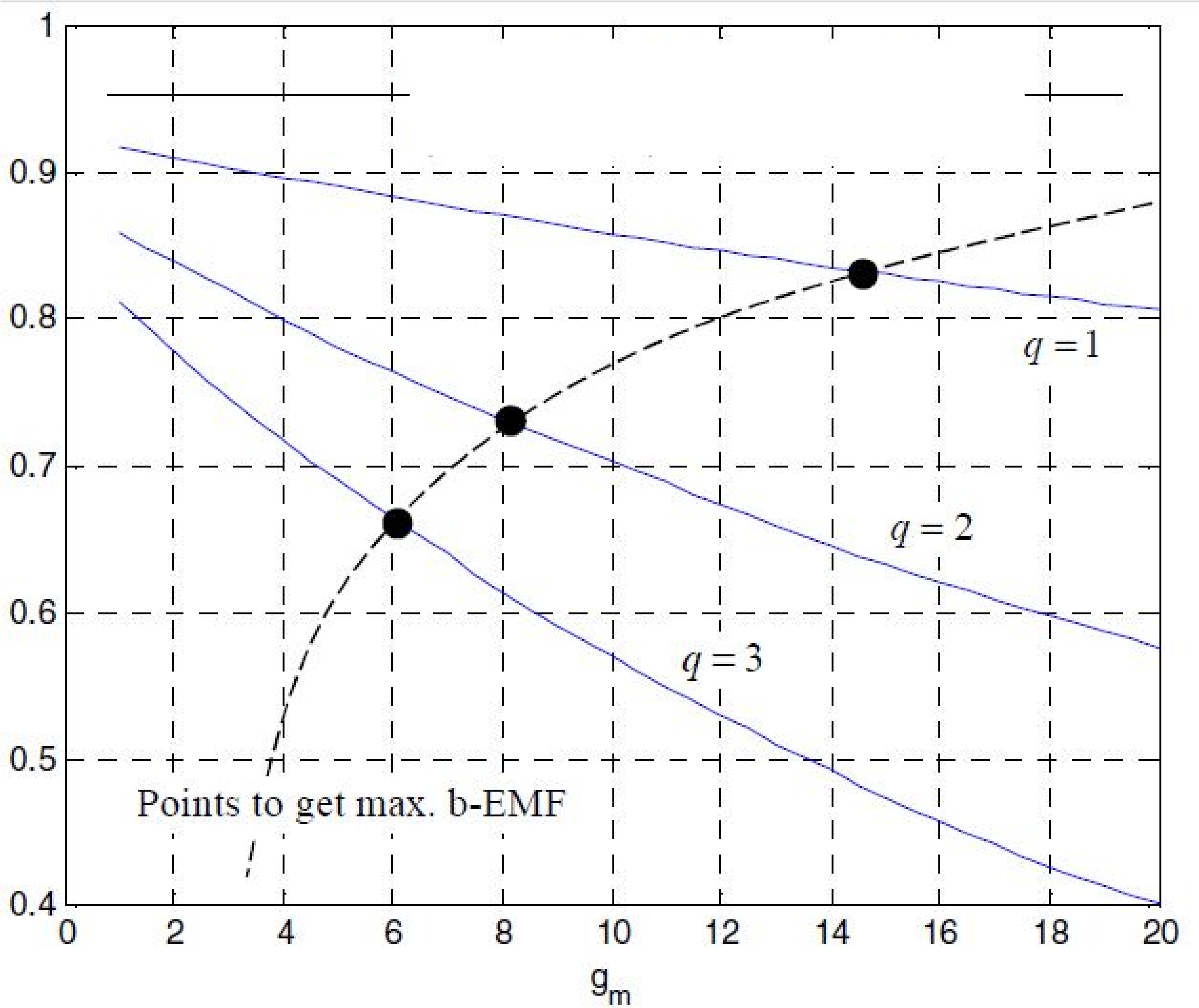


EMF Factor vs. q, g_a and g_m

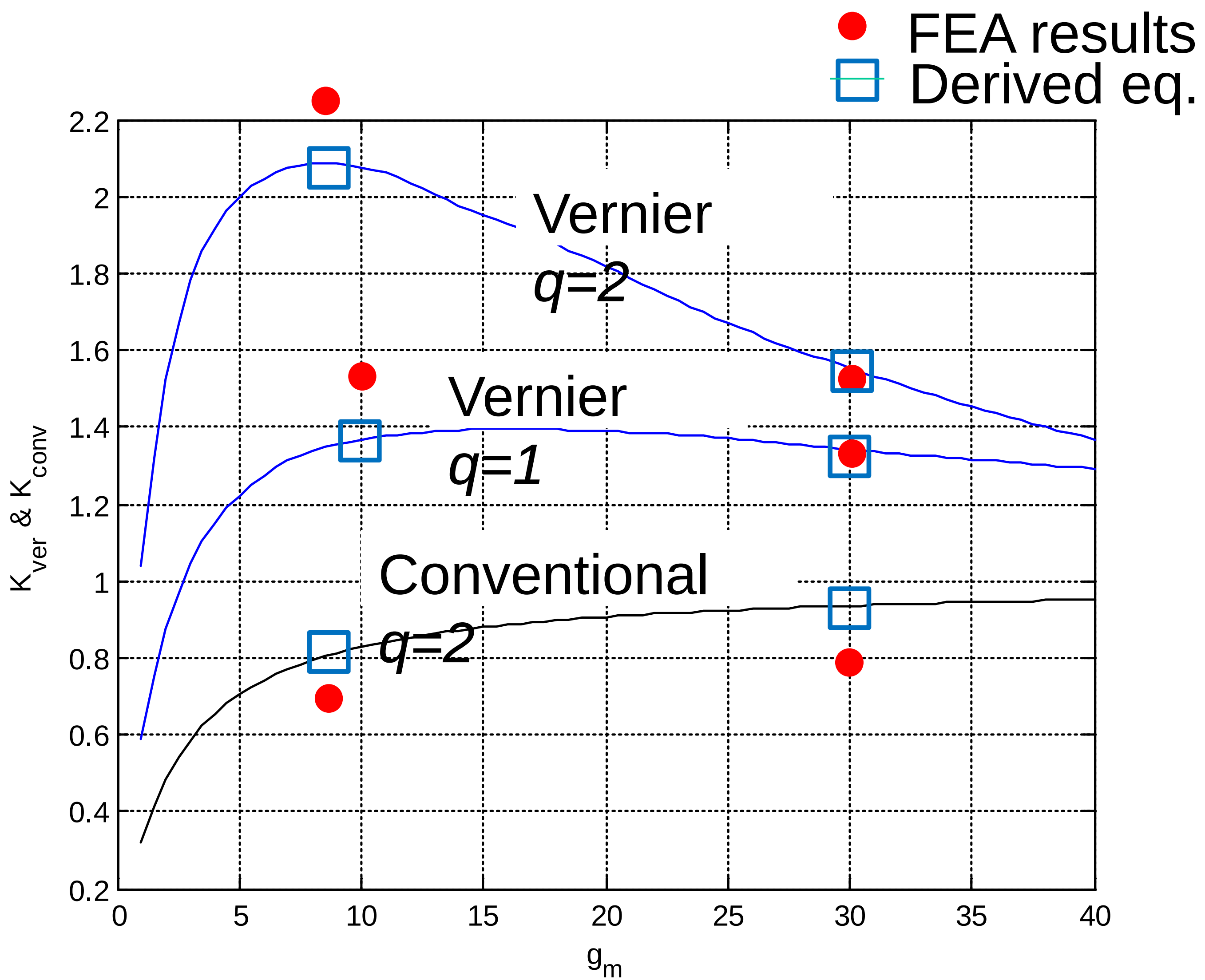
EMF Factor



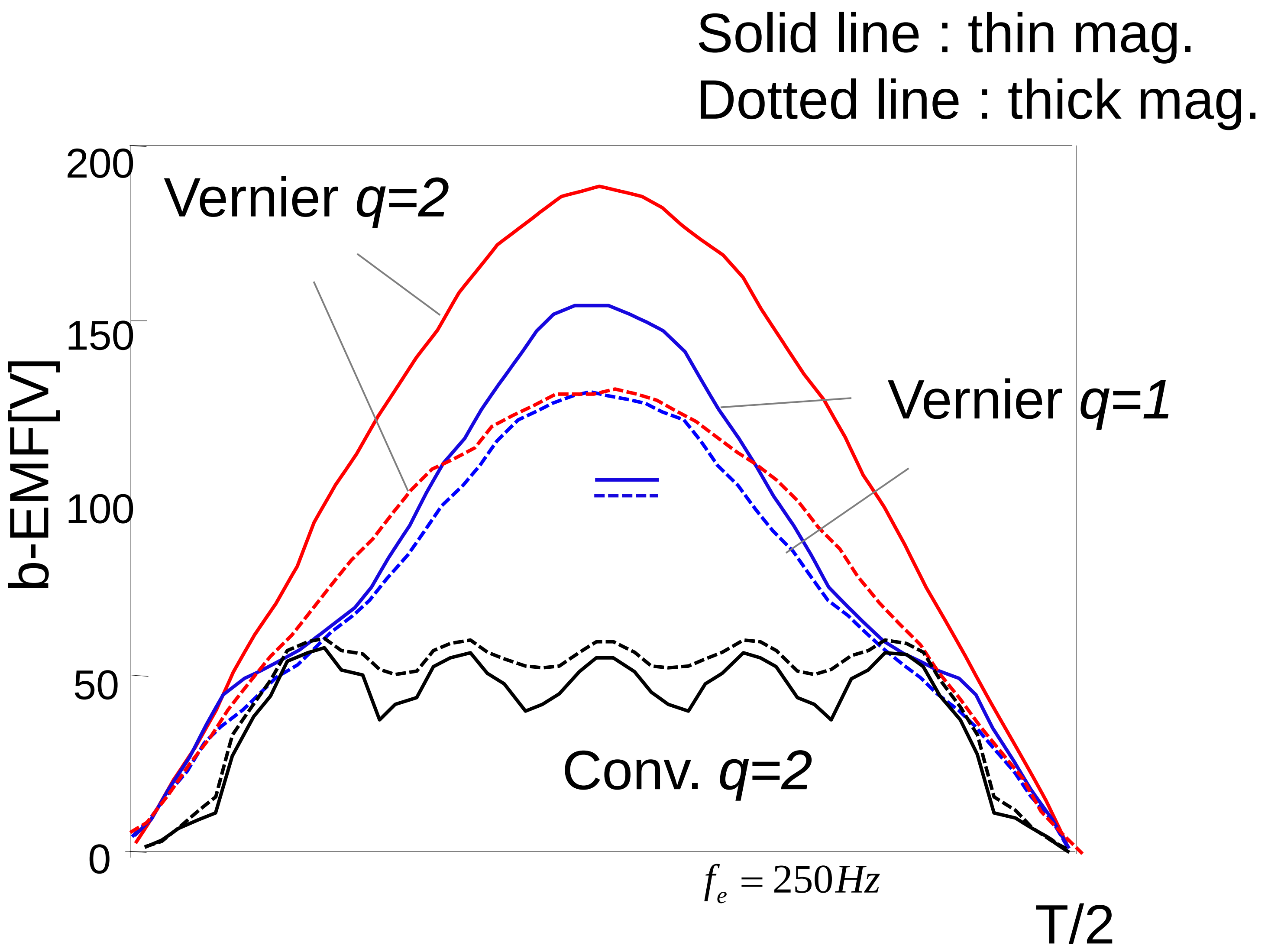
Power Factor vs. q and g_m



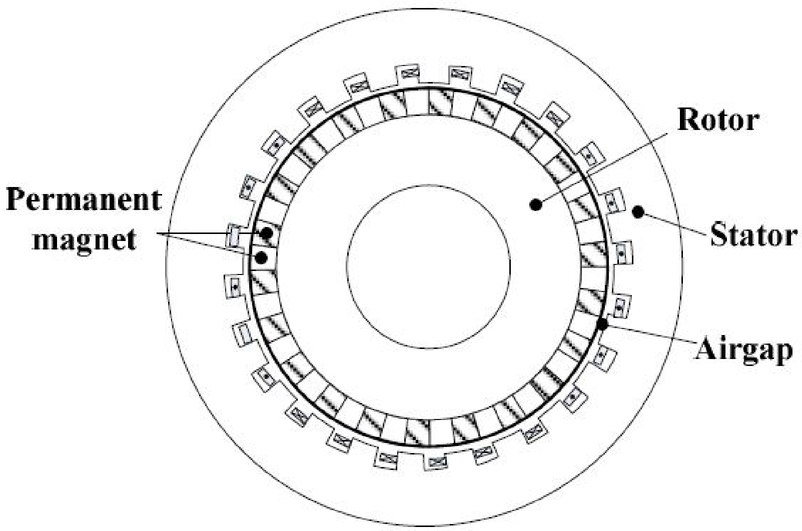
Analytical Equations Fully Verified by FEM



Back EMF Calculated with Finite Elements



PM Vernier Motor



- The torque producing capability of a PM vernier motor can exceed that of a conventional motor by 2-3 times with a power factor of 0.82
- For a 4 Pole Vernier to reach 1800 RPM requires a 300 Hz Supply
- A Ferrite PM Vernier Motor having the same size as a conventional Rare Earth PM motor but with better efficiency has been demonstrated using FEM

Time for questions?