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Sensorless Control of Permanent Magnet Motors

With internal permanent magnet motors, the high frequency signal injection method can deliver precise speed control without the need for a feedback sensor.

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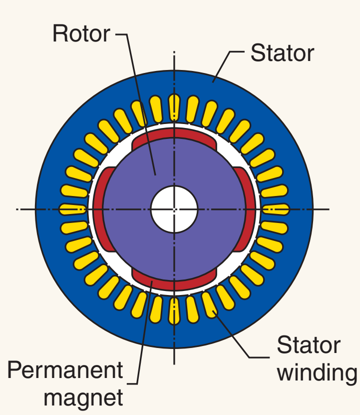
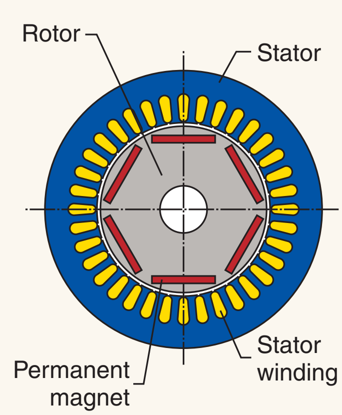
Precise speed control of AC motors is typically accomplished with a variable frequency drive (VFD) connected to a speed or position feedback sensor. In certain situations, however, it's possible to achieve a similar level of precision speed control without the need for a feedback sensor via the high frequency signal injection method.

To implement this method, the VFD must use open loop control, and it must be able to inject the required high frequency signal. The method only works with salient motors such as internal permanent magnet (IPM) synchronous motors.

Fig. 1 Motor structures



Surface mounted permanent magnet motor (SPM).

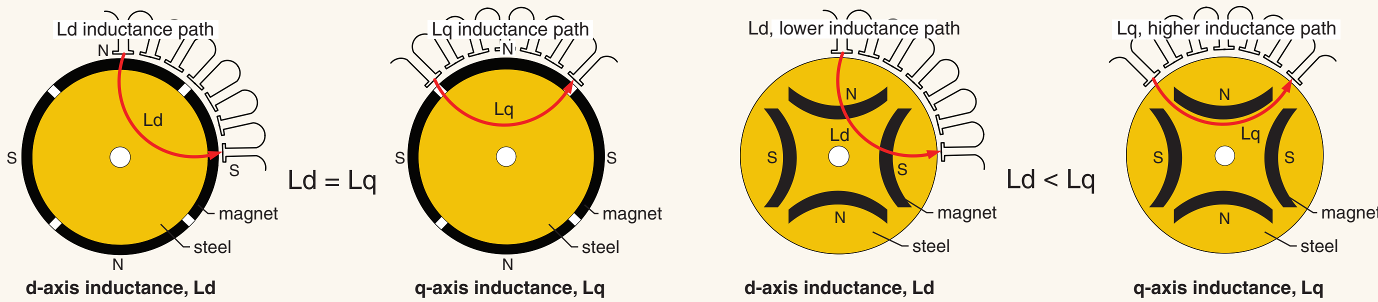


Interior permanent magnet motor (IPM).

Basic features of PM motors

Figure 1 depicts two common types of permanent magnet motors. The magnets of the surface-mounted permanent magnet (SPM) motor are attached on the surface of the

Fig. 2. PM motor magnetic saliency



Non-saliency characteristic of a SPM motor (Ld = Lq). *Saliency characteristic of an IPM motor (Ld < Lq).*

rotor, whereas those of the IPM motor are buried inside. Both motor types have high efficiency, but the IPM motor has additional torque because it utilizes both the magnet and reluctance torques generated by the magnetic saliency. Because the magnets of SPM motors need to be fixed on the rotor surface, mechanical strength is weaker than with IPM motors, especially in the high speed region. (View this article online to see a table comparing general features of SPM and IPM motors.)

PM motor magnetic saliency

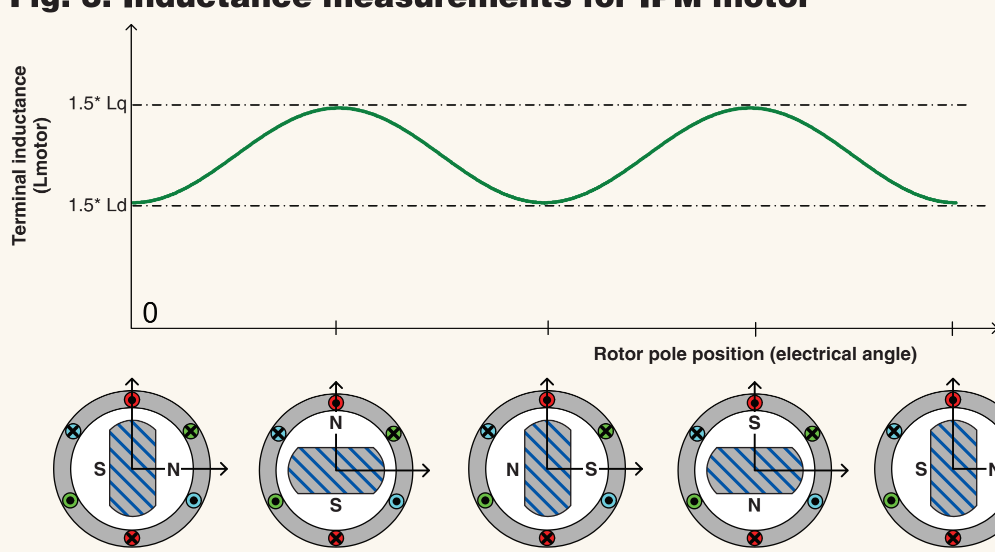
As shown in Figure 2, the effective air gap in the magnetic flux path of Ld and Lq are the same in SPM motors. The permanent magnets used in motors have very low permeability and can be regarded as air in inductance calculations. As a result, Ld is the same as Lq, therefore a SPM motor has very low inductance saliency. Thus, the inductance value measured at the motor terminal is constant regardless of the rotor position.

In an IPM motor, the permanent magnets are buried inside the rotor. Since the permanent magnets have lower permeability (that is, higher reluctance) than iron, the effective air gap in the magnetic flux path varies according to the rotor position. That variance is shown in Figure 3. This is called the magnetic saliency, and it results in variation of the inductance at the motor terminal according to the rotor position.

Figure 4 shows motor inductance measurements for an IPM motor. Figure 5 shows how the terminal inductance value changes according to the rotor position. The change can be expressed as the following equation:

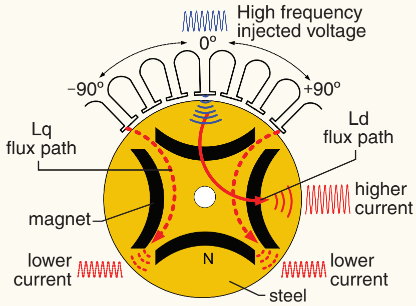
$$L_{rmotor} = 1.5\left[\frac{(L_d + L_q)}{2} + \frac{(L_d - L_q)}{2}\right]\cos 2\theta$$

Fig. 3. Inductance measurements for IPM motor



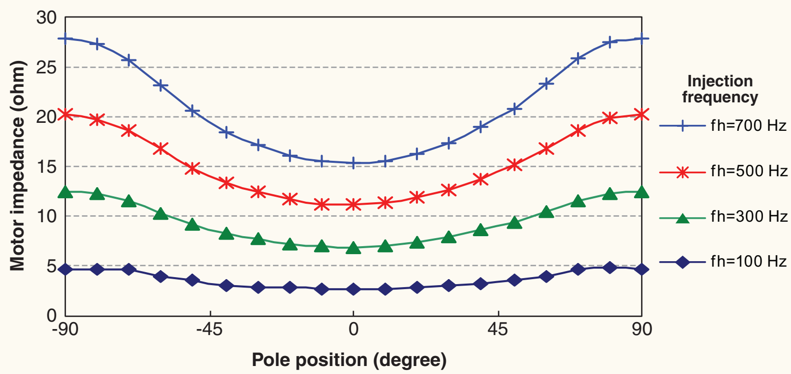
Variation of inductance according to rotor position.

Fig. 4. High frequency injection method



When high frequency voltage is injected, motor impedance changes.

Fig. 5. IPM motor impedance



IPM motor impedance variation according to injection angle.

An interesting characteristic to be noted from this equation: the rotor position can be detected by measuring inductance change. This characteristic enables rotor position detection for open loop vector control, that is control without the need for a speed or position sensor connected back to the motor drive to close the speed control loop.

High frequency signal injection method

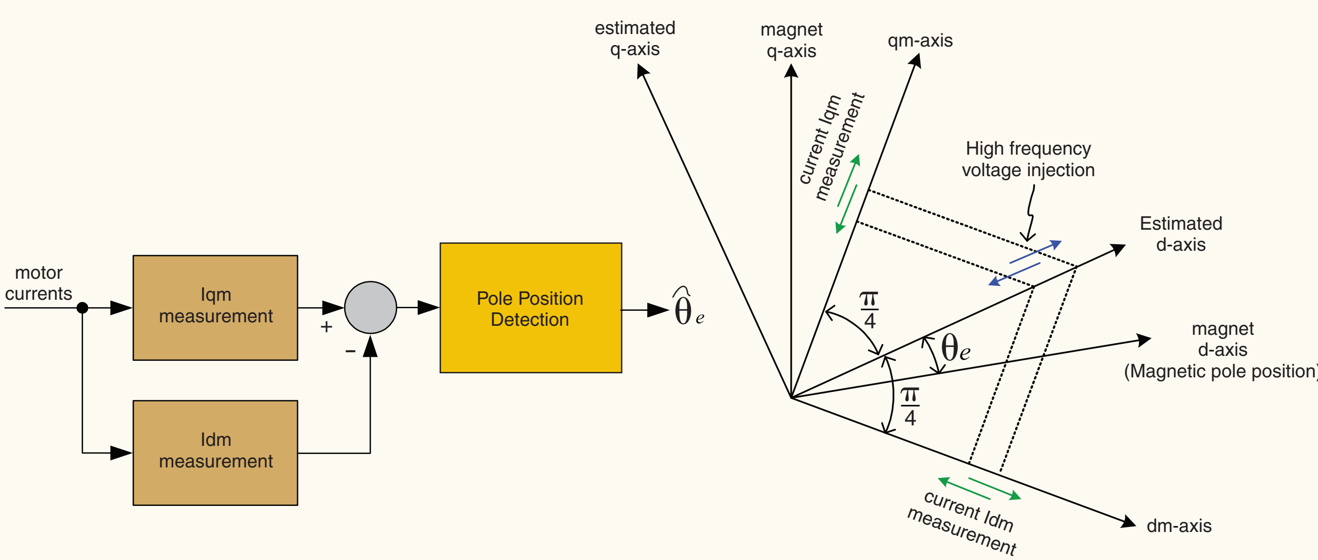
The basic concept of the high frequency signal injection method is that when a high frequency voltage is injected into an IPM motor with 0 degree injection angle (that is, through the Ld axis), the measured current will be at the highest level because of the lowest inductance. This indicates that motor impedance is at its minimum value, as shown in Figure 5.

When a high frequency voltage is injected to the motor with ±90 degree injection angle (that is, through the Lq axis), measured current is at its lowest level and motor impedance reaches its maximum value, also as depicted in Figure 5.

The position of the magnetic pole can thus be detected by using the saliency characteristics of Figure 5. Considering restriction in implementation, effective injection frequency ranges between 200 Hz to 1,000 Hz.

Here's how: Upon starting, a PM motor controller initially does not know the actual position of magnetic poles, so an arbitrary axis is presumed and defined as the d-axis or the magnetic pole axis. A high-frequency voltage signal is then injected on the presumed d-axis to track the actual magnetic pole position.

Fig. 6. High frequency injection method



Magnetic pole estimation using the high frequency injection method.

Motor currents are measured at both the dm and qm axes. If the estimated d-axis is not aligned to the real PM magnet axis, the measured high-frequency current components on the dm and qm axes are different. In the advanced open loop vector control algorithm, the estimated d-axis is adjusted until current difference i_{dm} - i_{qm} becomes minimum, aligning the estimated d-axis to the real magnetic pole axis.

Advanced open loop vector control via the high frequency injection method with an IPM motor provides speed control with a 1:100 range, speed response of 10Hz and accuracy, or plus or minus 0.2%. For applications where these speed control specifications are sufficient, this method is simpler and lower in cost than closed loop control with speed or position feedback sensor. **ce**

Jun Kang, Ph.D, is chief engineer for Yaskawa Electric America Inc. A significant reference for this article was Ide Kozo, et al, "Sensorless Drive Technology for Permanent Magnet Synchronous Motor," in Yaskawa Technical Review, Vol.69; No.2, 2005; pp.93-98.

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