Estimation of Permanent Magnet Temperature using d-axis Current for IPMSM

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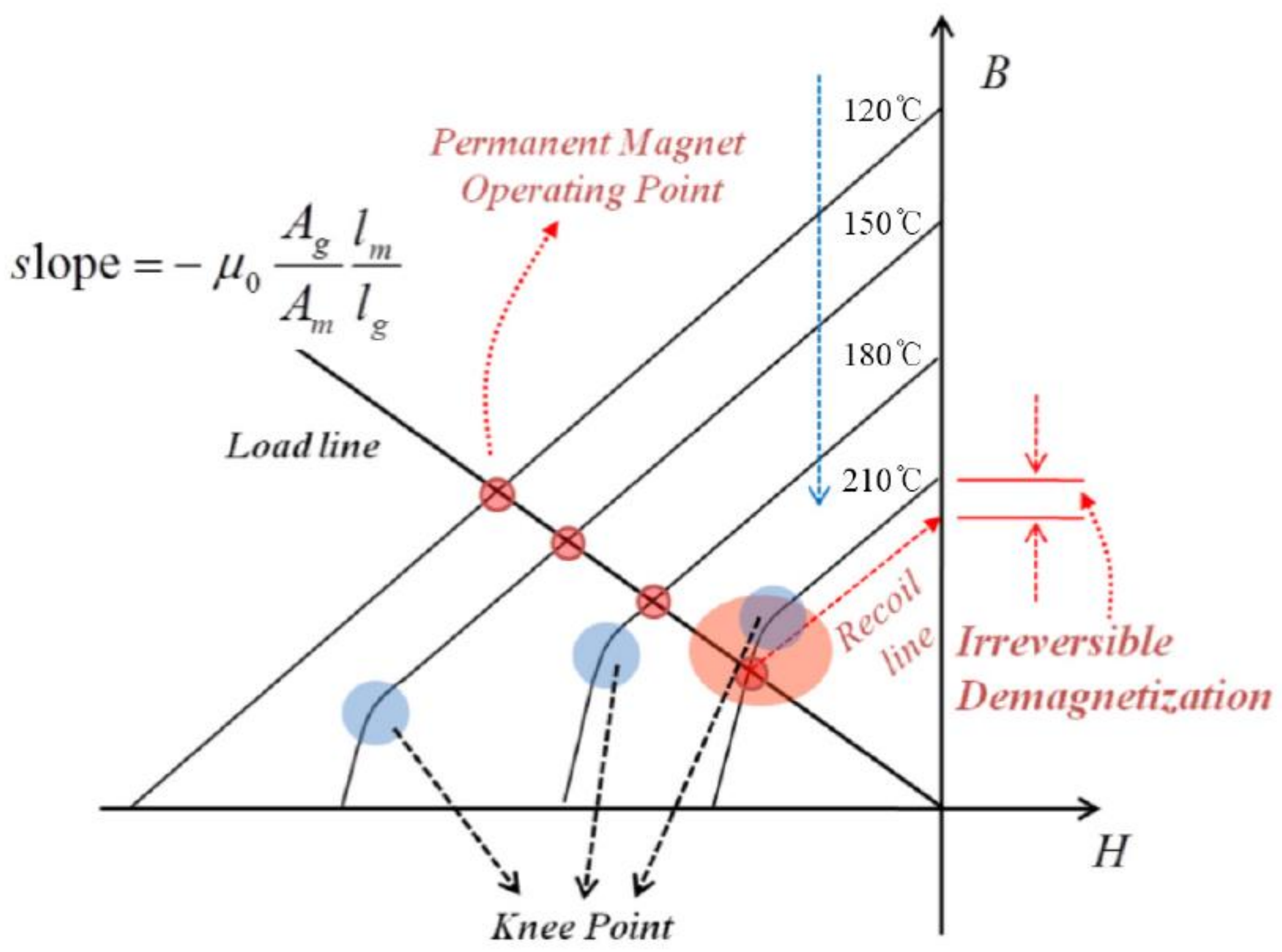
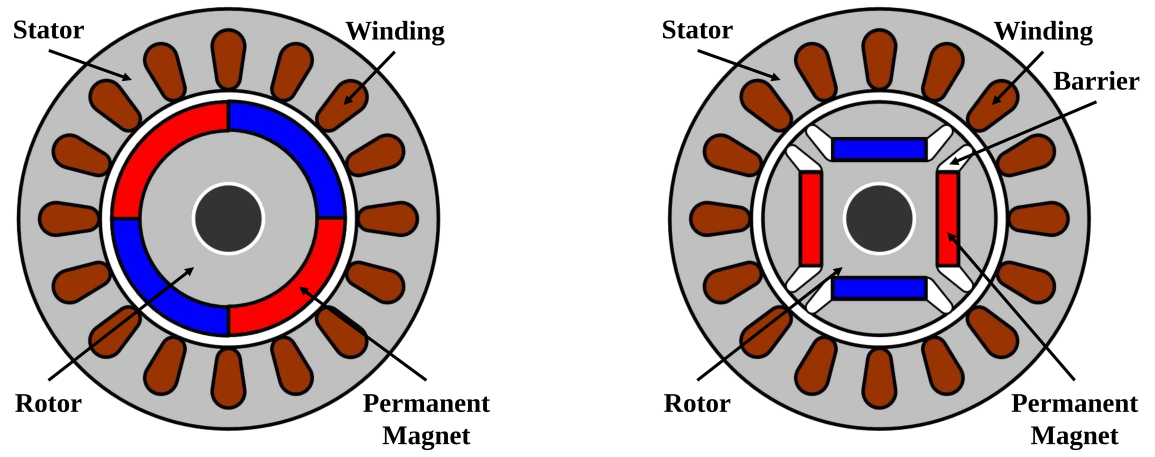
Background

Permanent magnet that is used interior permanent magnet synchronous motor used to be irreversibly demagnetized when the motor operate at high temperature. Therefore, the motor is designed considering irreversible demagnetization of permanent magnet. However, it is difficult to optimize motor design because we can't forecast the exact temperature of permanent magnet when the motor operate. In addition, it is difficult to measure the temperature of permanent magnet using thermocouple because of rotating the rotor. So, this paper proposes the method which it estimates the temperature of permanent magnet using reduction of d-axis current to know irreversible demagnetization of the permanent magnet.





$$B=\frac{\Phi_a}{A}$$

SPM $T=T_m=P_n\Phi_a i_q$ **Flux Linkage of PM**

IPM $T=T_m+T_r=P_n\Phi_a i_q+P_n(L_d-L_q)i_d i_q$

$$Temp_{PM}\uparrow \;\Rightarrow\; \Phi_a\downarrow \;\Rightarrow\; Torque\downarrow$$

Conclusion

- This paper will propose two methods for estimation of PM temperature. One is temperature estimation using torque equation and the other is temperature estimation using voltage equation.
- this paper will show the surface PM synchronous motor's(SPMSM's) PM temperature estimation, though the title of this paper is to estimate the temperature of interior PM synchronous motor's (IPMSM's) PM.

Permanent Magnet Temperature Estimation Algorithm

✓ Convention

Torque command → Current command → Torque generation → Increase in PM temp. → Decrease in linkage flux of PM → Torque Error (command & real value)

✓ Proposal

Torque command → Current command → Torque generation → Increase in PM temp. → Decrease in linkage flux of PM → Estimation of PM temp. → Estimation of torque

Permanent Magnet Temperature Estimation

$$\Phi_a=\Phi_a|_{ref}\left[1+k_{temp}\Delta T_{PM}\right]=\Phi_a|_{ref}\left[1+k_{temp}\left(T_{PM}-T_{PM}|_{ref}\right)\right]\qquad\left(\Phi_a|_{ref}=\frac{E|_{ref}}{\omega}\right)$$

Flux linkage equation by PM temperature

$$\begin{bmatrix}v_d\\v_q\end{bmatrix}=\begin{bmatrix}R_a&0\\0&R_a\end{bmatrix}\begin{bmatrix}i_d\\i_q\end{bmatrix}+\begin{bmatrix}0&-\omega L_q\\\omega L_d&0\end{bmatrix}\begin{bmatrix}i_d\\i_q\end{bmatrix}+p\begin{bmatrix}L_d&0\\0&L_q\end{bmatrix}\begin{bmatrix}i_d\\i_q\end{bmatrix}$$

Voltage Equation

$$v_q=(R_a+pL_q)i_q+\omega(\Phi_a+L_d i_d)$$

$$v_q=R_a i_q+\omega(\Phi_a+L_d i_d)$$

Φ_a

$$v_q=R_a i_q+\omega\left(\Phi_a|_{ref}\left[1+k_{temp}\left(T_{PM}-T_{PM}|_{ref}\right)\right]+L_d i_d\right)$$

$$\frac{v_q-R_a i_q}{\omega}-L_d i_d=\Phi_a|_{ref}\left[1+k_{temp}\left(T_{PM}-T_{PM}|_{ref}\right)\right]$$

$$\frac{\frac{v_q-R_a i_q}{\omega}-L_d i_d}{\Phi_a|_{ref}}-1=k_{temp}\left(T_{PM}-T_{PM}|_{ref}\right)$$

IPMSM

$$T_{PM}=\frac{v_q-R_a i_q-\omega L_d i_d-\omega\Phi_a|_{ref}+k_{temp}\omega\Phi_a|_{ref}T_{PM}|_{ref}}{k_{temp}\omega\Phi_a|_{ref}}$$

SPMSM

$$T_{PM}=\frac{v-R_a i-\omega\Phi_a|_{ref}+k_{temp}\omega\Phi_a|_{ref}T_{PM}|_{ref}}{k_{temp}\omega\Phi_a|_{ref}}$$

$$T_{PM}=\frac{v_q-R_a i_q-\omega L_d i_d-\omega\Phi_a|_{ref}+k_{temp}\omega\Phi_a|_{ref}T_{PM}|_{ref}}{k_{temp}\omega\Phi_a|_{ref}}$$

IPMSM

$$T_{PM}=\frac{v_q-\omega L_d i_d-\omega\Phi_a|_{0^\circ C}}{k_{temp}\omega\Phi_a|_{0^\circ C}}$$

($V_q >> R_a i_q$, Reference Temperature : 0℃)

$$T_{PM}=\frac{v-R_a i-\omega\Phi_a|_{ref}+k_{temp}\omega\Phi_a|_{ref}T_{PM}|_{ref}}{k_{temp}\omega\Phi_a|_{ref}}$$

SPMSM

$$T_{PM}=\frac{v-\omega\Phi_a|_{0^\circ C}}{k_{temp}\omega\Phi_a|_{0^\circ C}}$$

($V_q >> R_a i_q$, Reference Temperature : 0℃)

$$T_{PM}$$

$$\Phi_a=\Phi_a|_{ref}\left[1+k_{temp}\Delta T_{PM}\right]=\Phi_a|_{ref}\left[1+k_{temp}\left(T_{PM}-T_{PM}|_{ref}\right)\right]$$

$$T=T_m+T_r=P_n\Phi_a i_q+P_n(L_d-L_q)i_d i_q$$

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