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전기차량용 전동기의 파라메트릭 설계 및 동특성 연구

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Study on Parametric Design of Traction Motor and Dynamic Performance of Electric Vehicle

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Abstract - This paper study the dynamic performance of electric vehicle (EV) by analyzing the traction motor parameters. Using the interior permanent magnet synchronous motor (IPMSM) as the traction motor, the characteristics of motor, such as maximum torque, power factor, constance power speed ratio, and maximum speed are estimated by the saliency ratio of inductance and flux linkage. Then, the relationships between these characteristics and the dynamic performance of EV are established. Thus, the influence of the parameters of the traction motor on the dynamic performance of EV is revealed.

1. Introduction

Hybrid electric vehicle (HEV) and battery electric vechicle (BEV) are the most popular solutions for the issues of environment and nonrenewable resource. As GM launched the new type HEV, Volt, the series type HEV is getting more and more attention. In the series type HEV, the traction power is provided by electric motor only. The engine usually operates at the maximum efficiency state to charge the battery with a generator. Thus, the dynamic performance of the series type HEV is directly determined by the electric traction motoras well as BEV.

In addition, the characteristic of electric motor can be parametrically designed. Therefore, it is possible to find a relationship between the parameters of electric motor and performance of the series type HEV or BEV. Furthermore, the performance of HEV and BEV can be estimated by using the parameters of electric motor. Based on this idea, this paper first investigates the influence of main parameters on the characteristics of the interior permanent magnet synchronous motor (IPMSM). After briefly introducing the dynamic performance of vehicle, the relationship between the parameters of traction motor and dynamic performance of electric vehicle will be revealed.

2. Parametric Design of IPMSM

2.1 Parameter Normalization

The typical characteristics of IPMSM can be described with the normalized parameters [1]

$$I_n = \frac{I_a}{I_{am}},\ V_n = \frac{V_o}{V_{om}},\ \omega_n = \frac{\omega}{\omega_b},\ P_n = \frac{P}{V_{om}I_{am}},\ T_n = \frac{T\omega_b}{V_{om}I_{am}}$$
$$R_n = \frac{RI_{am}}{V_{om}},\ \psi_{mn} = \frac{\psi_m\omega_b}{V_{om}},\ L_{dn} = \frac{\omega_b L_d I_{am}}{V_{om}},\ \text{and}\ L_{qn} = \frac{\omega_b L_q I_{am}}{V_{om}} \quad (1)$$

where I_a and I_{am} are the line current and maximum line current in rms, V_o and V_{om} are the line-to-line voltage and maximum line-to-line voltage in rms, ω and ω_b are the electrical angular velocity and base electric angular velocity, P is the output power, T is the electromagnetic torque, and ψ_m is the flux linkage of permanent manget. Thus, it can be obtained that

$$\omega_{bn} = \frac{\omega_b}{\omega_b} = 1,\ I_{amn} = \frac{I_{am}}{I_{am}} = 1,\ \text{and}\ V_{omn} = \frac{V_{om}}{V_{om}} = 1 \quad (2)$$

2.2 Characteristics of IPMSM in Normalized Parameters

In the traction motor of HEV or BEV, the resistance of motor usually is so small that can be neglected for simplifying the analysis. Using the above normalized parameters, the voltage and torque equations of IPMSM can be described as

$$V_{dn} = -\omega_n \xi L_{dn} I_n \cos\beta = -\omega_n \xi L_{dn} I_{qn}$$
$$V_{qn} = -\omega_n L_{dn} I_n \sin\beta + \omega_n \psi_{mn} = \omega_n L_{dn} I_{dn} + \omega_n \psi_{mn}$$
$$T_n = \psi_{mn} I_n \cos\beta + \frac{1}{2}(\xi-1) L_{dn} I_n^2 \sin 2\beta = \psi_{mn} I_{qn} - (\xi-1) L_{dn} I_{dn} I_{qn} \quad (3)$$

where β is the current vector angle, and ξ represents the saliency ratio of inductance.

As known, the IPMSM can be controled in maximum torque per Ampere algorithm before base speed, or field weakening after base speed. Thus, at the base speed, both maximum current and maximum voltage are achieved, and both control algorithms are avaliable. According to the above voltage and torque equations, the current vector angle β in the MTPA control algorithm [1] can be described as

$$\sin\beta_m = \frac{-\psi_{mn} + \sqrt{\psi_{mn}^2 + 8(\xi-1)^2 L_{dn}^2}}{4(\xi-1)L_{dn}} \qquad (\xi \neq 1)$$
$$\text{and}\ \sin\beta_m = 0 \qquad (\xi = 1) \quad (4)$$

Meanwhile, the speed as a function of current vector angle when voltage $V_o = 1$ can be described as

$$\omega_n = \frac{1}{\sqrt{(\xi L_{dn}\cos\beta)^2 + (-L_{dn}\sin\beta + \psi_{mn})^2}} \quad (5)$$

and the power at this speed can be described as

$$P_n = T_n \omega_n = \frac{\psi_{mn}\cos\beta + \frac{1}{2}(\xi-1)L_{dn}\sin 2\beta}{\sqrt{(\xi L_{dn}\cos\beta)^2 + (-L_{dn}\sin\beta|\psi_{mn})^2}} \quad (6)$$

Thus, substituting (4) into (5), the L_{dn} can be calculated when $\omega_n = \omega_{bn} = 1$. The L_{dn} will be the function of saliency ratio ξ and flux linkage ψ_{mn} as

$$0 = L_{dn}^4[\xi-1)(\xi^2+1)^2] + L_{dn}^2[(2\xi^3 + \xi^2 - 4\xi + 2)\psi_{mn}^2 - 4(\xi-1)(\xi^2+1)]$$
$$+ [(3\xi^2-1)\psi_{mn}^4 - (5\xi-7)\psi_{mn}^2 + 4(\xi-1)] \quad (7)$$

For the given saliency ratio ξ and flux linkage ψ_{mn}, two real roots of L_{dn} can be obtained. Substituting them into the original equation, the correct value can be determined.

On the other hand, after obtaining the current vector angle of MTPA control, the maximum torque and rated power ($\omega_{bn} = 1$) can be calculated. The maximum torque (and rated power) in normalized parameters is

$$T_{kn} = P_{kn} = \psi_{mn}\cos\beta_m + \frac{1}{2}(\xi-1)L_{dn}\sin 2\beta_m \quad (8)$$

When (6) equal (8), the current vector angle β_p at the constant power speed can be deducted as

$$0=\sin^4\beta_b[(\xi-1)^2L_{dn}^2]+\sin^3\beta_p[2\psi_{mn}+(\xi-1)L_{dn}] \\ +\sin^2\beta_p[(1-\xi^2)L_{dn}^2P_{kn}^2+\psi_{mn}^2-(\xi-1)^2L_{dn}^2] \\ +\sin\beta_p[-\psi_{mn}L_{dn}P_{kn}^2-2\psi_{mn}(\xi-1)L_{dn}] \\ +\xi^2P_{kn}^2L_{dn}^2+P_{kn}^2\psi_{mn}^2-\psi_{mn}^2 \quad (9)$$

Substituting the calculated β_p into (5), the constant power speed and constant power speed ratio (CPSR) ($\omega_{bn}=1$) can be obtained.

3. Dynamic Performance of Vehicle

The major dynamic performance of vehicle includes the acceleration ability, gradeability, and maximum speed [2]. Generally, the acceleration ability is the most important performance because that it indicates the maximum traction power of the vehicle, while the gradeablity can reflect the maximum traction force of the vehicle. These three performance can be described as

$$P_{acc}=\frac{M_v}{2t_a}(V_b^2+V_v^2)+M_vgV_vf_r+\frac{1}{5}\rho_aC_DA_fV_v^3 \quad (10)$$

$$F_m=F_g+F_r=M_vgsin\theta+M_vgf_r \quad (11)$$

$$V_m=\sqrt{\frac{F_{Vm}-M_vgf_r}{\frac{1}{2}\rho_aA_fC_D}} \quad (12)$$

where M_v is the mass of vehicle, V_b is the base speed of vehicle, V_v is the speed of vehicle, f_r is the rolling resistance, ρ_a is the density of air, C_D is the aerodynamic drag coefficient, and A_f is the front area of vehicle.

The parameters of the study vehicle is listed in Table 1. This vehicle will be standard, and the analysis results will be compared with it.

<Table 1> Parameters of study vehicle

Terms	Value	Unit
Mass of vehicle	1200	kg
f_r	0.01	
ρ_a	1.205	kg/m^3
C_D	0.3	
A_f	2	m^2

4. Results and Discussion

4.1 Power of acceleration ability

Assuming that the $V_v=CPSRV_b$, the P_{acc} will be a function of CPSR. Figure 1. shows the relationship between the required power that the vehicle accelerates to 100km/h in 10s and the motor parameters.

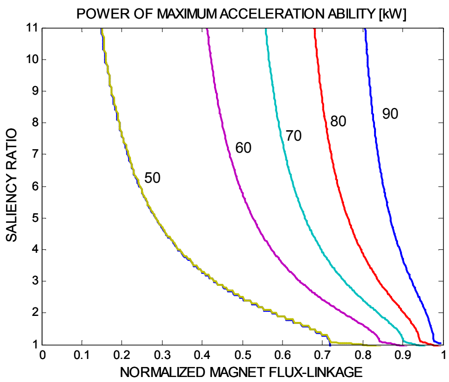

Figure 1. Power of acceleration ability and motor parameters

4.2 Angle of gradeability

Keeping the P_{acc} (with CPSR=3), the different CPSR will lead different maximum traction force. Thus, the maximum angle of gradeability with different motor parameters is calculated and shown in Figure 2. The 90o line is related to the infinite CPSR, which means the maximum traction force is infinite.

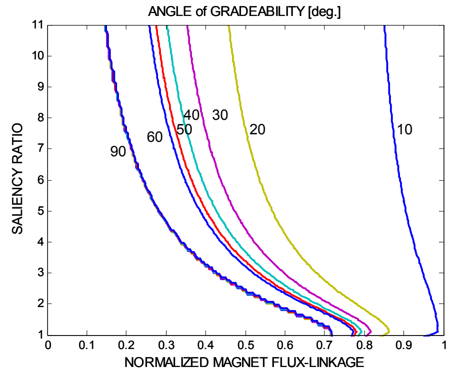

Figure 2. Angle of gradeability and motor parameters

4.3 Maximum speed

The maximum vehicle speed in fact is determined by the maximum force at the maximum speed. For the given power, the maximum force of the given speed is fixed. In order to find the relationship between the maximum vehicle speed and motor parameter, the rated power is considered. Thus, the maximum speed can be calculated by

$$P_{acc}=V_m(\frac{1}{2}\rho_aC_dV_m^2+M_vgf_r) \quad (13)$$

Solving (13), only one positive real root can be obtained. The contour map of maximum speed is shown in Figure 3. It can be seen that the maximum speed occurs when the motor has greater acceleration power.

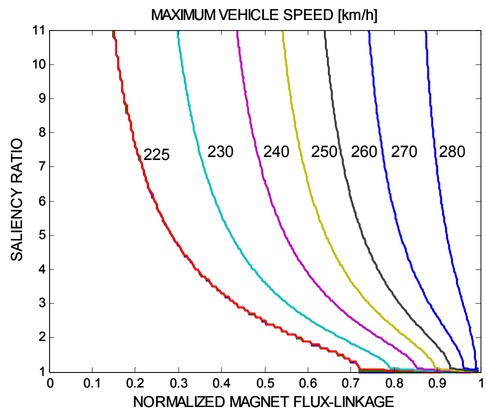

Figure 3. Maximum vehicle speed and motor parameters

3. Conclusion

This paper study the relationships between the motor parameters and dynamic performance of series type HEV or BEV. The motor parameters are normalized in order to indicate the typical characteristics. The acceleration ability, gradeability and maximum speed of the study vehicle are analyzed with different normalized saliency ratio and flux linkage of IPMSM.

[참 고 문 헌]

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