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주행조건을 고려한 LSEV용 SRM 설계

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Design of LSEV Switched Reluctance Motor Considering Drive Condition

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Abstract - Design of high efficiency Switched Reluctance Motor (SRM) for Low Speed Electric Vehicle (LSEV) is presented in this paper. The design is made from point of view to save more used energy for operating LSEV. Focus on saving the energy gives more efficiency can be produced. Based on applying suitable driving cycles and investigates the frequently power used are foundation to design the proposed motor. Meanwhile through Finite Element Analysis (FEA) characteristic of the proposed motor such as inductance and torque profile can be obtained.

1. INTRODUCTION

With increasing concern over the environment and ever stringent emissions regulations, the electric vehicle has been investigated as alternative form of transportation. Nowadays, battery electric vehicle(BEV), hybrid electric vehicles(HEVs), and fuel cell vehicles(FCVs) are developed. Even the energy sources are different, but one of core technology that is electric motor is need to produce enough propulsion. As high reliability and maintenance free operation are prime considerations for EV propulsion, Switched reluctance motor (SRM) is becoming attractive. SRM has a simple, low-cost, and robust machine structure due to absence of rotor winding and permanent magnets[1]. Switched Reluctance Motors is investigated for wide industrial applications due the mechanical strength and cost advantage[2]. There are some general combination of stator and rotor pole array of SRM, such as 6/4, 8/6, 12/8 and 16/12[3-4]. This paper is focus on 6/4 SRM structure.

2. MOTOR DESIGN FOR LSEV

2.1 Driving characteristic

The maximum speed of LSEV has 40km/h and total mass is 730kg. To satisfy the target performance, the requirement torque and speed should be calculated. The torque can be calculated from the gear ratio, dimension of wheel, and the drive force of EV. The drive force is calculated as following:

$$F_{drive} = F_{la} + F_{\omega a} + F_{rr} + F_{ad} + F_{hc} \tag{1}$$

$$F_{la} = ma \tag{2}$$

$$F_{\omega a} = J\frac{N_g^2}{\mu_g R^2}a \tag{3}$$

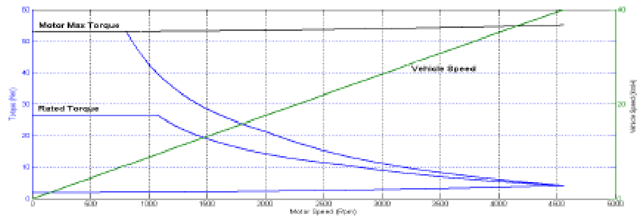
$$F_{rr} = C_{rr}\, mg\cos(\theta) \tag{4}$$

$$F_{ad} = \frac{1}{2}\rho A C_d V^2 \tag{5}$$

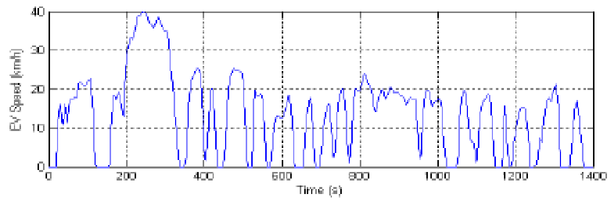
$$F_{hc} = mg\sin(\theta) \tag{6}$$

Where C_{rr} is the coefficient of rolling resistance, C_d is Air Drag Resistance Coefficient, ρ is the density of the air [kg/m³], A is the frontal area [m²] and N_g is the gear ratio.

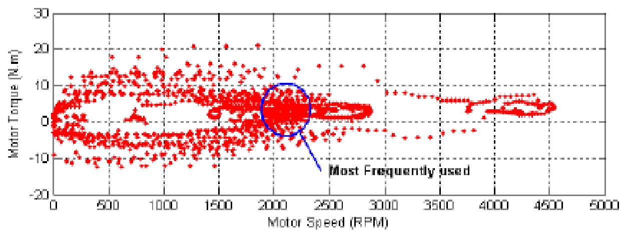
The calculation gives maximum torque and maximum speed of the motor must be achieved, it is shown as motor characteristic curves in Fig. 1. When required parameters are obtained, analysis of most frequently used speed and torque can be calculated by applying the Federal Urban Driving Schedule(FUDS) as shown in Fig. 2. The result gives spread data about driving behavior in urban area, as shown in Fig. 3. Ranges of the most frequently speed and the most frequently torque used for driving in urban area shown in Fig. 4 and Fig. 5, respectively.



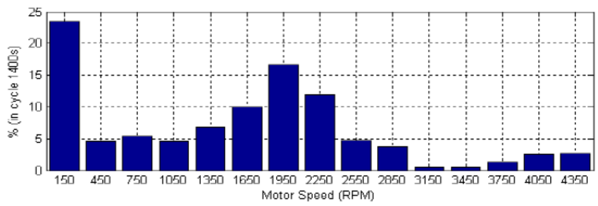
<Fig 1> Motor Characteristic Curves



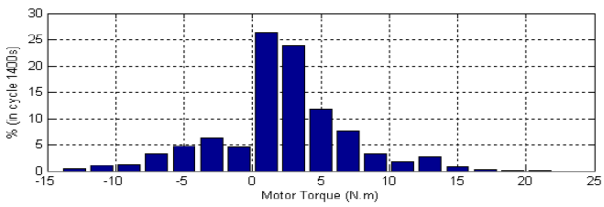
<Fig 2> Federal Urban Driving Schedule(FUDS)



<Fig 3> Spread Driving behavior in urban area

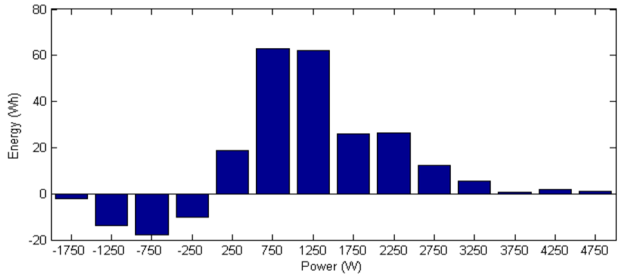


<Fig 4> Range of the most motor speed



<Fig 5> Range of the most motor torque

In order to optimize the driving efficiency of electric vehicle, energy consumption in every range of speed and torque has been analyzed and shown in power to energy graph as seen in Fig. 6. From the analyzed of most motor speed, torque and energy consumption used in urban area, the effective motor torque and speed are selected on 3.5 N.m at 2200 RPM. This torque and speed is becoming main requirement in motor design.



<Fig 6> Energy Cunsumption

2.2 Motor Design Analysis

Fixed the bore diameter, the length of motor can be obtained from:

$$L = \frac{T}{k_d k_e k_3 k_2 (BA_s) D^2} \qquad (7)$$

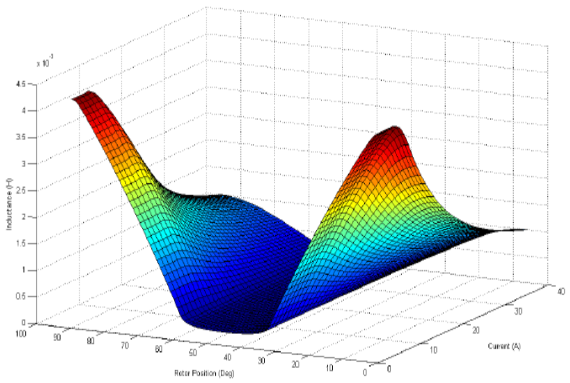
Where K_d is a duty cycle, K_e is efficiency, k_2 and k_3 is a constant, B is flux density, A_s is an electric loading and parameters D is bore diameter.

Pole arcs of the stator and rotor are important parameters in motor design. More optimal motor power output can be achieved by using the accurate stator and rotor poles arc, in this paper 33 [Deg] for rotor arc and 31[Deg] for stator arc are selected with considering of torque can be produced and efficiency that can be achieved.

From the mechanical specifications and performance of 6/4 SRM, the rated output power of the proposed motor is 3 kW. Table 1 shows the specification and dimension of proposed SRM.

<Table 1> Specification and dimension of proposed SRM

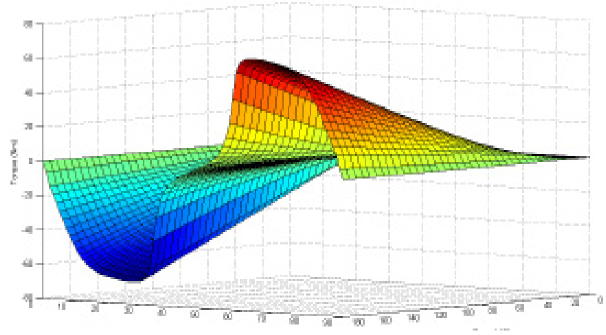
Parameter	Value	Parameter	Value
Dia.Shaft	30 [mm]	Air-Gap	0.3 [mm]
Dia. of Stator	182 [mm]	Rotor Pole arc	33[Deg]
Dia. of Rotor	103.4 [mm]	Stator Pole arc	31[Deg]
Stack Length	185 [mm]	Turn No./Phase	24 [Turn]
Resistance/phase	0.016 [ohm]	Max. Current	170 [A]
Rated Current	100 [A]	Max. Torque	53 [N.m]



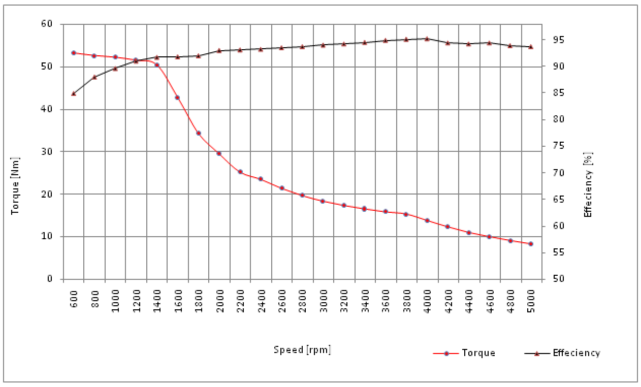
<Fig 7> Inductance Profile of the proposed SRM

3. PERFORMANCE OF PROPOSED MOTOR DESIGN

The inductance profile and torque profile of the proposed SRM are analyzed with the Finite-Element-Analysis (FEA), as seen in Fig. 7 and Fig. 8. Otherwise the Speed-Torque and efficiency curve exhibited in Fig. 9.



<Fig 8> Torque profile of th proposed SRM



<Fig 9> Speed-Torque and Efficiency Curves

The proposed motor can be achieved 53 N.m at 600 rpm for the maximum torque, 7.3 kW at 1400 RPM for the maximum power. Focused point is 3.5 N.m at 2200 RPM with 91.8% efficiency can be reached.

4. Conclusion

Design of a high efficiency SRM for LSEV is presented in this paper. Based on analysis of the driving behavior from the FUDS, the most efficiency in order to save more energy has been observed. Selecting point from torque and efficiency is the important, butin sufficient detail there is a variegated energy consumption used. By selecting the most effective energy consumption point, a better efficiency of a motor can be achieved. The performance of proposed design motor is shown in this paper.

Acknowledgment

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