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Development and Design of 35KW Low-Noise IPM Motor for Micro Electric Vehicles

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Abstract

Since the electric vehicle uses an electric motor, problems have arisen as the driver hears the inherent noise of the motor or external noise, which was not a problem in the past, due to the overall lower noise environment than when using an internal combustion engine. Therefore, the purpose of this paper is to reduce the noise and vibration of electric motors for electric vehicles, and recently, to increase the speed of high-power, high-efficiency electric motors in a small size, and to develop low-noise motors, IPM motors are applied to produce 35KW electric motors for electric vehicles. A motor for low noise was designed and implemented.

N-T Curve and efficiency map were confirmed as the final result of developing a 35KW low-noise motor for electric vehicles by applying the IPM motor applied in this paper. Based on 3500 rpm, Max Torque [Nm]: 121.15, Max Power [KW]: 44.04, and Max Efficiency [%]: 97.65, showing high efficiency.

Keywords: *IPM, PM, SPM, BEM, N-T Curve, Efficiency map*

1. INTRODUCTION

The fact that electric vehicles do not emit harmful substances such as exhaust from vehicle driving, generate electricity using regenerative braking when decelerating/stopping, and store this electric energy in a battery to reuse it, thereby enabling a dramatic improvement in fuel efficiency. As a solution to coal fuel depletion, many studies are being conducted [1] [2]. In addition to performance/efficiency issues such as high-efficiency drive motors and extended battery usage time, the development of these electric vehicles also requires solving problems such as heat dissipation [3], stable operation and reliability of electric motors and batteries under extreme environmental conditions.

In addition, since electric vehicles use electric motors, they are known for their low noise compared to vehicles using internal combustion engines [4]. However, by using an electric motor instead of an internal combustion engine, noise problems, which were not a problem in the past, have emerged due to an overall reduced noise environment.

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This paper aims to develop a low-noise IPM (Interior Permanent Magnet) motor to improve the structural characteristics of the drive motor, which is the cause of motor noise that is offensive to the emotions of the occupants in electric vehicles.

Therefore, the purpose of this paper is to reduce the noise and vibration of electric motors for electric vehicles, and recently, to increase the speed of high-power, high-efficiency electric motors in a small size, and to develop low-noise motors, IPM motors are applied to produce 35KW electric motors for electric vehicles. We want to design and develop low-noise motors.

2. RESEARCH CONTENT

2.1 Structure of electric vehicle drive motor

A new problem with electric vehicles is that they are too quiet. As the sound of the drive motor of the electric vehicle becomes quiet, driving noise, wind noise, and decelerator whine noise are felt more loudly, and accordingly, reduction efforts are required. In particular, in the case of a motor used for the purpose of driving a vehicle instead of an engine, related research such as generation of electric pure sounds peculiar to the motor has not been sufficiently advanced.

As driving motors of electric vehicles, PM (Permanent Magnet) motors and induction motors using permanent magnets are mainly used. PM (Permanent Magnet) motors use permanent magnets instead of rotor windings, so they do not need to supply power to the windings, so they are highly efficient, and the longer the operation time, the lower the maintenance cost compared to standard motors. PM motors are divided into SPM (Surface Permanent Magnet) motors with permanent magnets attached to the rotor surface and IPM (Interior Permanent Magnet) motors with permanent magnets embedded in the rotor [5].

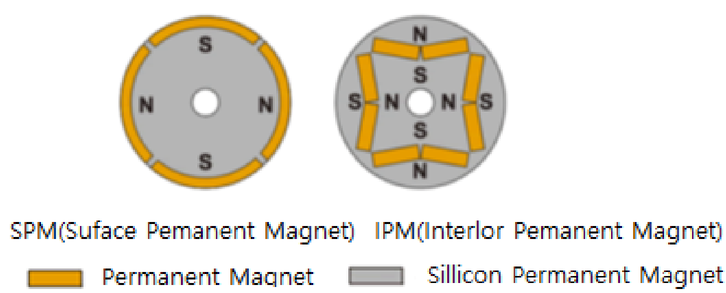

Figure 1. Examples of SPM and IPM structure types

In the case of the PM motor, the main sources of electromagnetic noise/vibration are torque ripple and cogging torque. Torque ripple is given as the product of the basic cycle of ripple, which occurs six times per electrical cycle in the case of a three-phase drive motor, and the "number of pole pairs per mechanical revolution. And cogging torque occurs as the least common multiple of the number of poles and slots. Example of combination of slot and number of poles assuming a combination of 16 poles and 24 slots occurrence of an excitation source of 48th torque ripple and 48th cogging torque the excitation source of torque ripple and cogging torque overlap can be found. Electromagnetic designs that are disadvantageous in terms of noise/vibration are often adopted for electrical performance. In order to solve this problem, countermeasure design for noise/vibration reduction is very important from a mechanical point of view.

2.2 Noise of driving motor of electric vehicle

Figure 2 is an order cut corresponding to the electromagnetic order in the noise measurement results according to the rotational speed of the drive motor of the electric vehicle. To analyze the peak band with high noise in the order cut, the fundamental frequency component is obtained for the number of revolutions of each order peak band in the line speed-noise diagram of Figure 2, and the frequency of the generated noise can be found by multiplying the corresponding order [4].

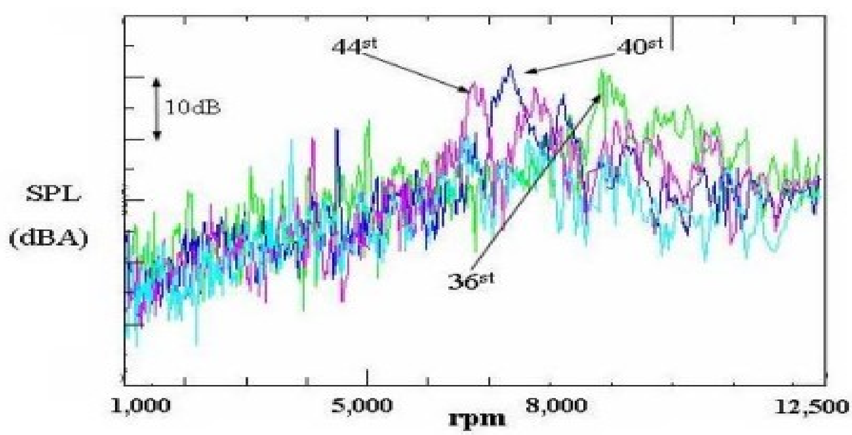

Figure 2. Graph of noise caused by motor structure

As shown in Figure 2, the main noise band when operating from 1,000 to 12,500 rpm is the 5 to 6 kHz band. As the motor rotational speed increases, the noise peak tendencies generated sequentially from higher order have a structure that occurs when the electromagnetic excitation source has a specific structure mode, thereby showing the characteristics of noise.

3. DESIGN OF IPM MOTOR FOR 35KW LOW NOISE

This paper was designed with the performance target shown in Table 1 to develop a low-noise IPM motor for 35KW for electric vehicles.

Table 1. Performance target of low-noise IPM motor for 35KW

Parameter		Target spec	Remarks
Performance	**Maximum torque**	120Nm @ 3500rpm	
	Rated torque	70Nm @ 3500rpm	
	Rated speed	3500 rpm	
	Max RPM	7500 rpm	
	Maximum efficiency	95% above	
Voltage spec	**Battery voltage**	320 ~ 360 Vdc	
Core size limit	**Outer diameter**	Φ 175 mm below	
	Laminated	110 mm below	
Speed Sensor		Resolver	
Insulation rating		H	Max 180℃

The characteristics specifications required for the performance target of the low-noise IPM motor for 35KW in Table 1 applied the maximum torque, maximum output, rated rotation speed, and maximum motor efficiency in terms of performance. In addition, as inverter specifications, battery voltage and maximum current were applied, and motor design specifications applicable to micro electric vehicles were presented to improve noise.

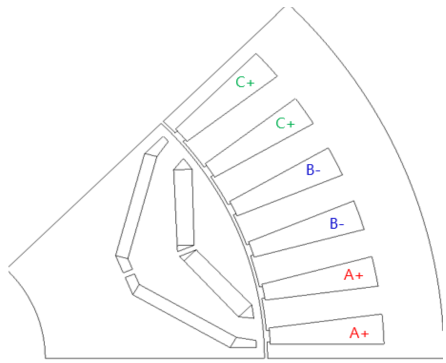

Figure 3. Design of motor sizing

The model specifications according to the sizing design of the motor in Figure 3 are as follows. Looking at the application contents according to the sizing design of the motor, the constant (3 phase), the number of slots (48 slots), and the number of poles (8 poles) were applied, the outer diameter of the stator (175mm) and inner diameter (117mm), the outer diameter of the rotor (116mm), and the outer diameter of the rotor (116mm). Stator and rotor (35PN210) and magnet (N42UH) were applied for inner diameter (43.9mm), air gap (0.5mm), stacking length (102mm), and design materials.

4. IMPLEMENT

In this paper, sizing design model specifications and electromagnetic simulations were conducted according to the performance target of a 35KW low-noise IPM motor. Figure 4 shows the no-load characteristics, and the simulation was conducted with a counter electromotive force (VII rms) of 37.71 based on 3500 rpm. As a result, torque [Nm]: 120.106 and output [KW]: 44.02.

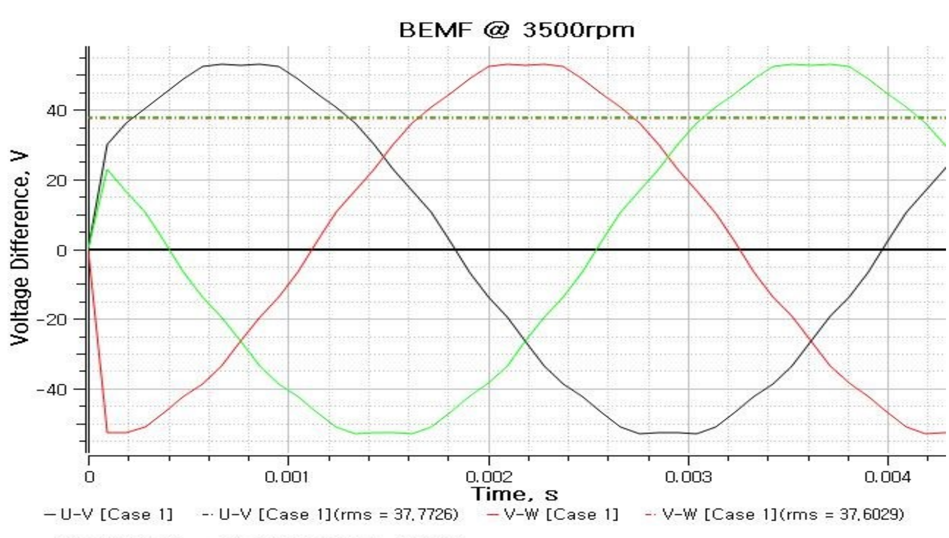

Figure 4. BEMF waveform of no-load characteristics

To confirm the final result, the N-T curve and efficiency map were checked. As a result, as shown in Figure 5, Max Torque [Nm]: 121.15 and Max Power [KW]: 44.04 based on 3500 rpm.

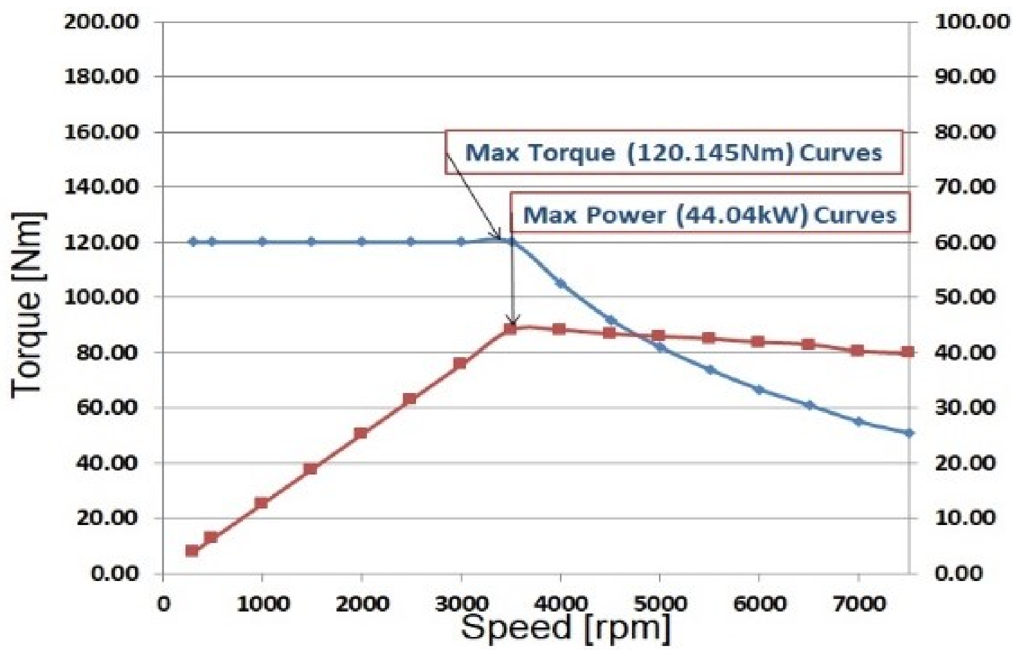

Figure 5. BEMF waveform of no-load characteristics

The efficiency map in Figure 6 showed high efficiency with Max Efficiency [%]: 97.65 based on 3500 rpm.

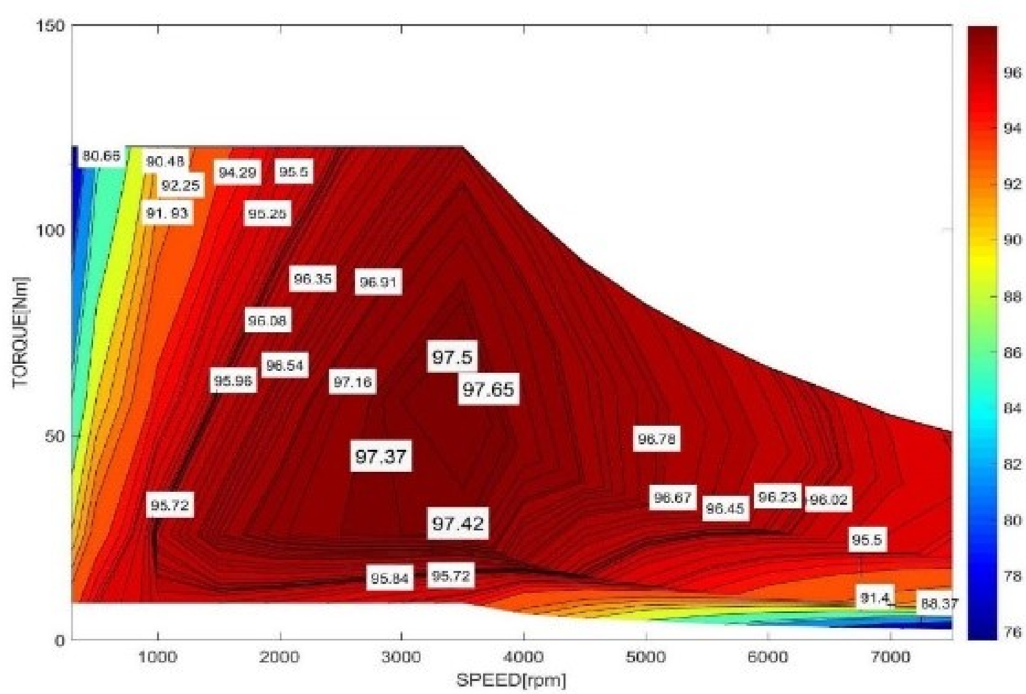

Figure 6. Efficiency map

5. CONCLUSION

Since electric vehicles use electric motors, they are known to be quieter than when using internal combustion engines. However, due to the overall reduced noise environment, problems arise as the driver hears noise inherent in the motor or external noise, which was not a problem in the past. This paper develops a low-noise IPM (Interior Permanent Magnet) motor to improve the structural characteristics of the drive motor that cause motor noise that is offensive to the emotions of the occupants in these electric vehicles.

Therefore, the purpose of this paper is to reduce the noise and vibration of electric motors for electric vehicles, and recently, to increase the speed of high-power, high-efficiency electric motors in a small size, and to develop low-noise motors, IPM motors are applied to produce 35KW electric motors for electric vehicles. A motor for low noise was designed and implemented.

As a result, as the simulation contents according to the no-load characteristics, the counter electromotive force (VII rms) based on 3500 rpm was 37.71, the torque [Nm]: 120.106, and the output [KW]: 44.02. In addition, the N-T curve and efficiency map were confirmed. Based on 3500 rpm, Max Torque [Nm]: 121.15, Max Power [KW]: 44.04, and Max Efficiency [%]: 97.65, showing high efficiency.

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