JPE 4-2-4

Design and Control of SRM For LSEV Drive

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ABSTRACT

This paper presents an application of SRM drive for LSEV(Low Speed Electric Vehicle). In this paper, a 5[kW] SRM for a traction of a LSEV is to design and investigate the characteristics of the drive system. The main design parameters and control strategy are given. In the control method, a current control, for the soft-starting technique at a starting operation, is adopted. In the high speed range, an angle control technique is implemented, for a high efficiency drive of SRM. Some experimental tests are executed to find the drive performances.

Keywords : LSEV, SRM drive, Angle control, Soft start

1. Introduction

Environmental pollution has become a world-wide issue recently. Strenuous efforts have been made for a long period of time as to the promotion of wider use of the electric vehicle as a low-pollution vehicle, for the electric vehicle poses no air pollution problem caused by exhaust gases nor noise pollution problem. Legislative initiatives such as the Californian clean air act impose considerable constraints on the car manufacturers in other to enable the development of new drive concepts such as hybrid and pure electric vehicles.

In recent years, also the SRM emerges as a candidate for the drive train of electric vehicles. The leading objective of all proposals to use blushless motor (IM, SRM, BLDCM etc.) in electric vehicles is to eliminate the commutation problem and so to achieve a higher availability. One of the attractive features of SRM is the possibility of maintaining full power over a wide speed range.

Manuscript received April. 15, 2003; revised March. 4, 2004
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However, using AC motors bring a heavy penalty on cost first, the control equipment is always more expensive, often by a gross margin. The SRM proposal is an attempt to minimize this penalty. The cost of the electrical components of motor is very less than for an equivalent induction motor[1-5].

In this paper, a 5[kw] SRM drive for application of LSEV is to design and investigate the characteristics of drive system. The main design parameters and control strategy are given. In the control method, a current control, for a soft-start at the starting operation, is adopted. In the high speed range, an angle control is implemented for a high efficiency drive of SRM.

2. Configuration of Control System

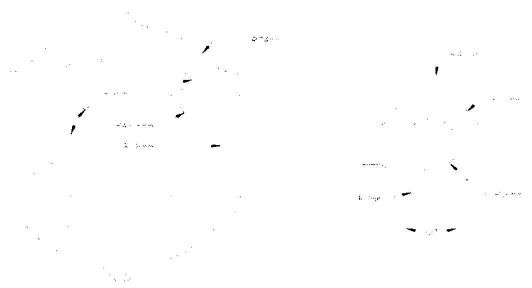
2.1 Design of Prototype Motor

The specifications of SRM designed for the LSEV are summarized in Table 1. The dimensions are restricted in the design stage for applying target vehicle.

Fig. 1 shows a cross-sectional view of the prototype motor, and its flux density and magnetizing curves are illustrated in Fig. 2. From the simulation results, flux distribution and density, which is under 1.8[T], and flux linkage are adequate for a traction drive[4].

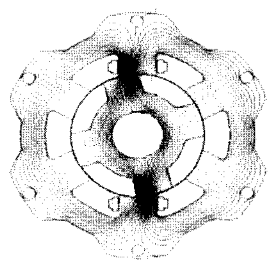
Table 1. Specification of SRM for LSEV.

Item	Specification
Output power	5[kw](continuous) / 13[kw](2min.)
Voltage	72[V] (50~90[V])
Torque	20[Nm](4000[rpm]) /62[Nm](2000[rpm])
Weight	16[kg] below
Efficiency	80% over
Speed	Golf (20km/h), Street (54km/h)
Noise	65 [db] below

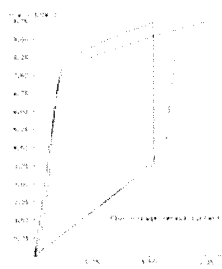


(a) stator (b) rotor

Fig. 1. Cross-sectional view of the prototype SRM.



(a) flux density plot



(b) flux linkages vs. phase current

Fig. 2. Flux analysis of the prototype SRM.

2.2 Speed Control Strategy

Fig. 3 shows torque-speed curve of a motor. Under the base speed ω_b, the regulation of current controls the torque developed. Because the back-emf is low at this speed region, the allowable maximum current can be supplied to the motor; therefore, it is limited by torque capability. In the region between ω_b and ω_c, the current is hard to increase sufficiently because of the effect of back-emf.

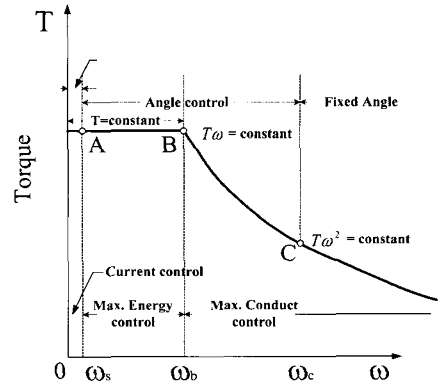


Fig. 3. Torque-speed characteristic curve.

Therefore, during this region, switching angle control is a possible control method. It might be employed to find an optimal efficiency and to minimize the torque ripple. According to the position of switch on angle, wide speed range can be obtained. It maintains a constant torque although core and resistance losses are increased considerably.

In general, it can sustain a constant torque up to two or three times than that of base speed. After ω_b, the switching angle is fixed to avoid continuous exciting. The continuous exciting happens when the exciting angle is over half of the pole-pitch of rotor. This can be limited under the value by means of core loss and other factors. In this region, current is reduced and torque is proportional to the square of speed term with the speed.

Under the base speed, current control is generally applied. It is a control that ignores the intrinsic characteristics operated at low switching frequency. In this region, the switching angle control is sometimes used to increase the efficiency.

2.3 Control of Drive System

Fig. 4 shows the block diagram of overall controller.

The position information is given by the encoder connected with the motor shaft through outer clock terminal of timer 1. From the position information mixed with the timer 2, speed information is obtained per sampling period 200[μs]. The speed controller is operated only once during 10 sampling times; thus, the sampling period of speed controller becomes 2[ms]. Due to the speed error (6), proportional and integral control are used. At start-up, the command torque is produced by the addition of outputs of a proportional controller and an integrating one. And the current (11) for producing a flat-topped torque is determined by the current table that is made in advance, considering the phase overlap that depends upon the amplitude of command torque and rotor position angle. When the command torque is over rated, it is limited up to the rated torque in order to protect devices using the anti-windup control method. After start-up, speed control is performed by the energy conversion ratio control, i.e., the proposed angle control.

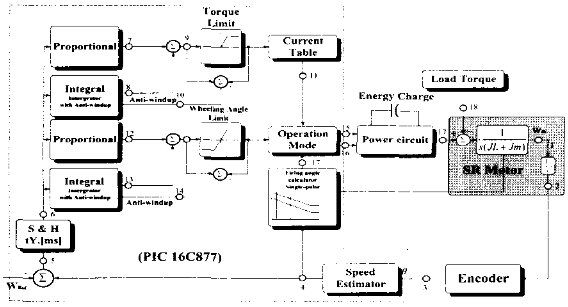


Fig. 4. Configuration of overall controller.

Fig. 5. Test set-up and vehicle.

The controller uses the one-chip microprocessor PIC16C877. It has 8 bit CMOS with the RISC architecture and 200 [ns] interruption. It also includes EEPROM, 10 bit A/D converter, D/A converter, serial communication port, and watchdog timer. By using this control board, the input signals for controlling the electric vehicle are produced from the accelerator, brake, and digital brake. Specially designed IGBT has 400 [A] rated current.

Because of the higher current rate, DC link is designed as an aluminum flat board, and it employs RC snubber to protect from an instantaneous over voltage.

3. Experimental Results

To verify the theoretical analyses and to find a proper magnetizing angle from experiments, a high performance SRM drive system was manufactured. For basic experiment, the load uses a 5 [kW] shunt dc generator, and then it was tested equipped with the LSEV.

3.1 Converter for a Rapid Current Demagnetizing

The converter for the drive system is a multilevel c-dump type shown in Fig. 6. It is advantageous to build-up current rapidly and to reduce demagnetizing time[7]. Fig. 7 shows the experimental waveform of phase voltage, phase and C-dump current. It was tested on steady-state under the command speed 4000[rpm] at 700[W] and 3.5 [kW], respectively. From the experi mental results, with 700 [W] load, magnetizing, wheeling, and demagnetizing periods appear at approx. 7°, 23°, and 2°, respectively. In the case of 3.5 [kW], their regions are 10°, 20°, and 5°, respectively. As shown in the figure, to obtain a fast demagnetizing, double the magnetizing voltage is applied, and the recovered condenser voltage is used to settle current rapidly.

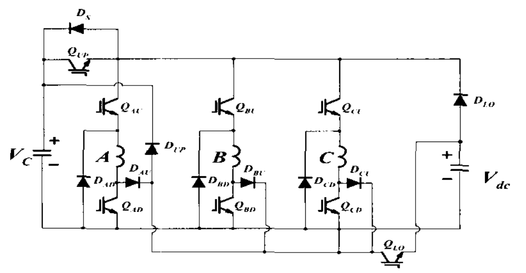
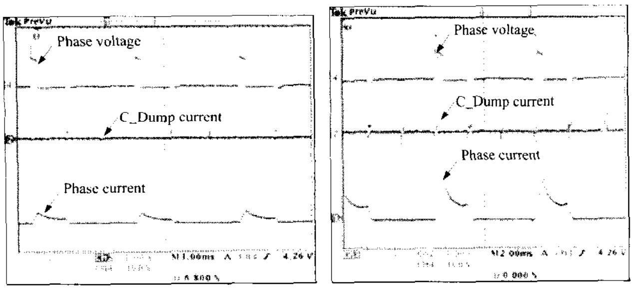


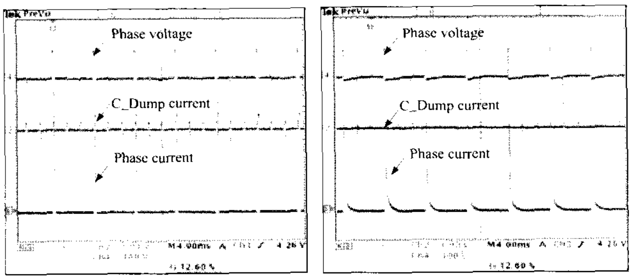
Fig. 6. Multilevel C-dump converter for traction drive.

Since the recovered energy in Fig. 7(a) is very small compared to that of Fig. 7(b), and the displacement is also much smaller. Consequently, the torque utilize region of proposed converter can be enlarged thanks to the excellent ability of current demagnetizing and in setting magnetizing currents.



(a) 700[W] load (b) 3.5[kW] load

Fig. 7. Voltage and current waveforms of proposed inverter.



(a) conventional method (b) proposed method

Fig. 8. Voltage and current waveforms according to control methods at 500[W] load.

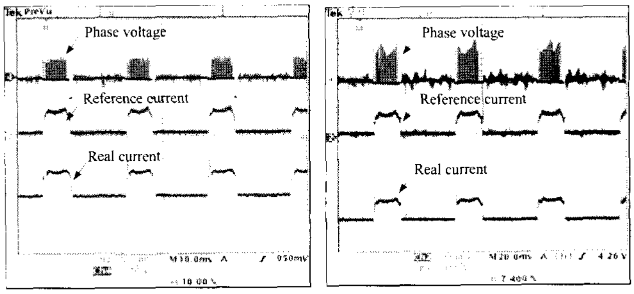
3.2 Switching Method for a Maximum Energy Ratio

Fig. 8 shows the experimental waveforms of phase voltage, phase current, and C-dump current. The proposed method is compared with the conventional method under similar magnetizing and demagnetizing voltage. It shows the result waveform at the command speed 2500[rpm] and output power 500[W]. At the beginning of the wheeling mode, a back-emf exists due to a large current; therefore, fast demagnetizing is possible. However, according to the decreasing of current, it becomes a near constant value because of a reduced back-emf. Consequently, when the demagnetizing voltage is applied, the current is completely demagnetized. In the flowing current through C-dump capacitor, the positive current is used when magnetizing voltage is applied, and the negative one shows the recovered current when it is in the demagnetizing mode.

3.3 Characteristics of Starting and Braking

Fig. 9 shows the experimental waveform of phase voltage, command current, and real current when it is operated to develop a constant torque at start-up speeds of 250 [rpm] and 500 [rpm], respectively.

The end of start-up mode is determined by the efficiency of SRM and the inertia of electric vehicle.



(a) 250[rpm] (b) 500[rpm]

Fig. 9. Reference and real current at start-up.

In this experiment, it was set to 500 [rpm] from several repeated experiments. From the waveform, real current follows the command value. A current controller that has a constant peak value is employed, and its switching frequency is set to 20 [kHz]. Due to the flat-topped torque developed by current control, it operates stably at the start-up region. The current control mode finishes at 500 [rpm], ans the angle control method is applied after the speed.

Fig. 9(a) shows the characteristic during a start-up speed of 250 [rpm], and Fig. 9(b) illustrates the waveform at the end of current control method at 500 [rpm]. At the start of current command value, the real current does not perfectly follow the reference current due to lower inductance, but it follows sufficiently at the last period.

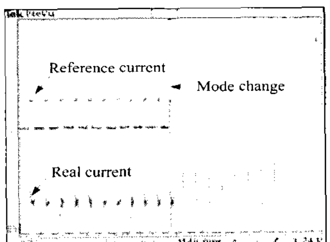


Fig. 10. Reference and real current at starting.

Fig. 9 shows the experimental waveform of the com -mand and real phase current to investigate the transition procedure from start-up to angle control mode. The current command value produces a flat-topped torque at the start-up is changed to the rated current value when the prior mode finishes. It limits the rated current regardless of distortions during angle control region.

In the SRM drive of the electric vehicle, it is difficult to guarantee the continuity of the output power between current control and angle control modes.

To achieve a soft control when the mode is in transition, exciting angle control should be performed to generate the same torque as the prior current control mode. To solve the problem, the angle producing a continuous torque at the transition is given as the initial value of the integrator; hence, speed characteristic is sufficiently improved.

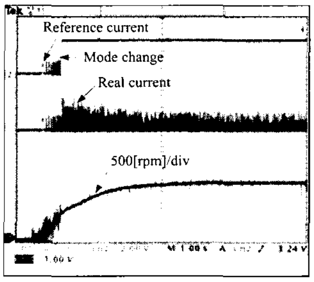


Fig. 11. Reference and real current at starting using soft control technique.

Fig. 11 shows the experimental waveforms of command current and real phase current. From the waveforms, we can find the converting process changed from start-up mode to angle control mode. At start-up, the command value for building up flat-topped torque is changed to rated value after the start-up mode is finished. This is the reason that if over rated current is generated by the unwanted distortion during the angle control, it limits the current below the rated one.

4. Conclusions

In the SRM drive for an electric vehicle, general drive methods are not suitable because of its variable load conditions. The SRM drive is usually classified into two main control methods. One is to control switching on/off angles, and the other is to control the level of current.

Theoretical analysis and experimental results are presented in detail. They are summarized as the following:

First, a novel inverter, in order to increase the output power by increasing duty ratio resulting in a faster demagnetizing period, is proposed. The maximum output power of the proposed system using the prototype equipped with SRM for the LSEV is increased compared with that of the conventional method.

Secondly, a new magnetizing method with a low -frequency increasing the energy conversion ratio that is related to the efficiency of motor is proposed. As a result, it is advantageous to improve the efficiency and to decrease the noise level.

This work has been supported by a grant No. R01-2001-000-00300-0 from Korea Science and Engineering Foundation.

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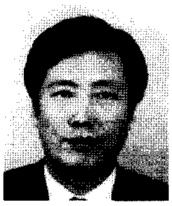

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