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A Low Cost Position Sensing Method with Optical Sensors for Switched Reluctance Motor

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ABSTRACT

Considering the start-up and economical efficiency, the optical sensor technique using a slotted-disk and an opto-interrupter are appropriate, however, this method needs three opto-interrupters and a slotted-disk when driving the 6/4 pole SRM(switched reluctance motor). In this paper, we propose an economic method by replacing the conventional opto-interrupter and slotted-disk with only optical sensor which enables the motor to start up and forward and reverse operation. Also the control circuit includes only analog devices, which makes the process more economical.

Keywords: Optical sensor, SRM, Opto-interrupter

1. Introduction

Generally the position sensor represents the important factor in SRM drives. In fact, in order to obtain good performances and low torque ripple, a high-resolution sensor is needed, which is costly and usually needs a special construction for the machine. So researchers are becoming aware of their cost and are exploring the possibility of cost reduction.

Rotor position sensing is an integral part of SRM control because of the nature of reluctance torque production. In fact, excitation of the SRM phases needs to be properly synchronized with the rotor position for effective control of speed and torque. We have investigated the possibility of the reduced position sensor for SRM drives with advanced control technique..

A shaft position sensor is usually employed to determine the rotor position. However this is not always appropriate, considering economical efficiency in case of using the incremental encoder, there is a problem at start-up as it is not easy to track down the location of rotor at the very beginning. Considering the start-up and economical efficiency, the optical sensor technique using a slotted-disk and an opto -interrupter are appropriate, however this method needs three opto-interrupters and a slotted-disk when driving the 6/4 pole SRM.

In this paper, we propose an algorithm needing only two optical sensors to control 6/4 pole SRM including start-up operation. By removing the slotted-disk and reducing the optical sensor, it improves the convenience and economical efficiency of the SRM control. The proposed method is implemented in a simple analog circuit instead of using an expensive DSP.

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2. Proposed Optical-Sensor Method

2.1 The conventional method

Fig. 1 shows the conventional position detecting method by opto-interrupters and a slotted-disk. Generally by using three opto-interrupters and a slotted -disk, it is possible to measure the position of rotor and determine the excitation point of each phase exactly without using an expensive encoder.

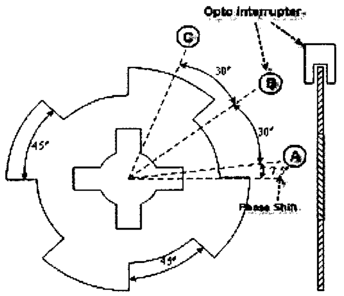


Fig. 1 Rotor position detection by opto-interrupters and slotted -disk

Table 1 shows that the bi-directional(forward and reverse) operation is only possible with three or four optical sensor in accordance with the number of phase. It needs three sensors to drive a three-phase 6/4 pole SRM[1]. However, this paper proposes a method that only needs two optical sensors to control the bi-directional operation.

Table 1 Bi-directional operation with three or four sensors

Motor Type	3 phase 6/2 pole	3 phase 6/4 pole	3 phase 12/8 pole	3 phase 8/6 pole
Number of sensors	3	3	3	4
Sensors spacing	60	30	15	15
Disk slot	90	45	22.5	22.5
Disk tooth	90	45	22.5	37.5
Number of slots	2	4	8	6

2.2 Position sensing technique

Fig. 2 shows the rotor position sensing method where the rotor is plated with a reflector so that it could respond to optical sensor [2].

In this paper, to detect rotor position when the salient poles are passing the optical sensor, we painted the salient poles of SRM as light and dark parts like as shown Fig. 3(c) and also attached optical sensor(Fig. 3(a)) in the side of stator slot like Fig. 3(b). So we can substitute the function of slotted-disk and opto-interrupter for optical sensor. As a result, it is possible to produce a compact motor and also simplify the manufacturing process.

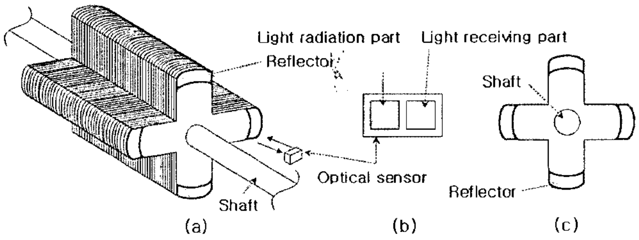


Fig. 2 Used position sensing method
(a) Equipment of SRM position sensor
(b) Optical sensor (c) Structure of reflector

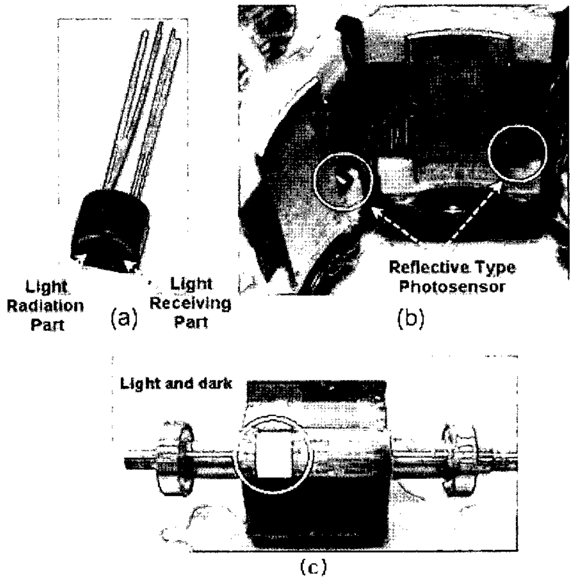
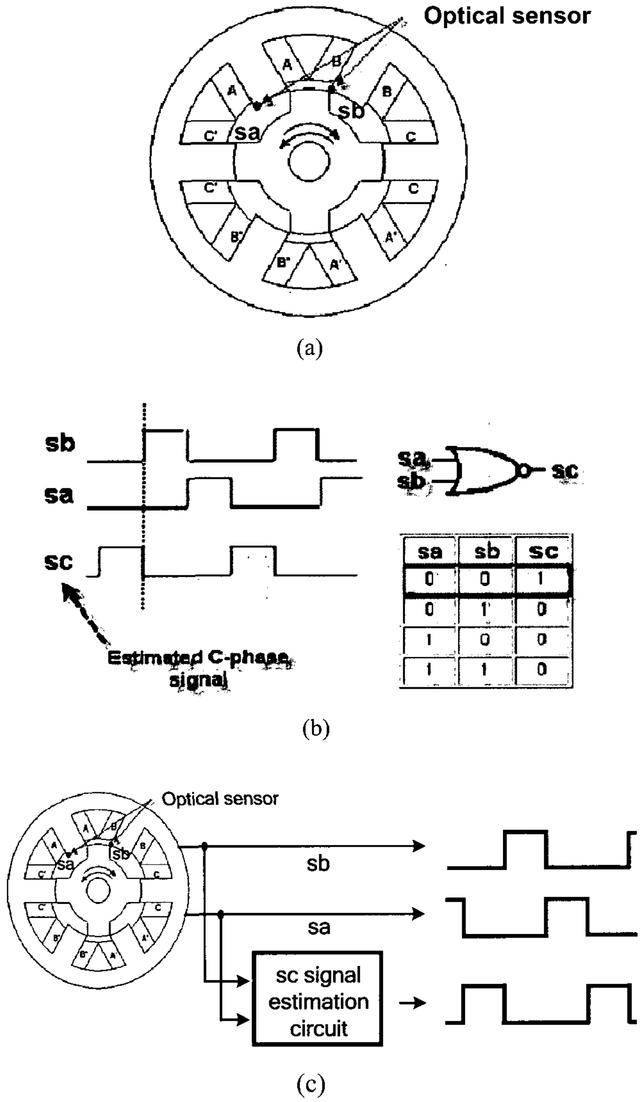


Fig. 3 Proposed rotor position sensing method.
(a) Optical sensor (b) Sensor that installed at SRM
(c) Light and dark parts of rotor

2.3 Rotor position sensing technique using two Optical sensors

In this part, we have investigated the possibility of the reduced position sensor for SRM drives with advanced control technique. In case of using two optical sensors, the position of two phases is naturally detected by the actual optical sensors and the other phase should be detected by the combination of signals of actual optical sensors.

The mechanism to generate the other phase signal from the actual optical sensor signals can be explained as follows: The optical sensor 'sa' and 'sb' are attached to each pole as shown Fig. 4(a). Then 'sc' signal is estimated by the two signal 'sa, sb' and a NOR circuit shown in Fig. 4(b). With this simple technique, we determine exactly the excitation point of 6/4 pole SRM in forward or reverse operation. Fig. 4(c) shows 'sa', 'sb' and estimated sc signal by the proposed method. The estimated 'sc' signal should have high level while the signal of 'sa' and 'sb' are low level.



sa	sb	sc
0	0	1
0	1	0
1	0	0
1	1	0

Fig. 4 Proposed algorithm
(a) Position sensor (b) Algorithm of estimated sc signal
(c) sa, sb and estimated sc signal

But if the initial rotor position is exactly located between 'sa' and 'sb', it can't make start up due to low-level signal on every phase. Therefore to overcome this problem, we use the NOR circuit so that start up is always possible even when the 'sa' and 'sb' have low-level signals. The proposed circuit is so easy to implement and it also reduces the system cost.

3. Simulation Results

In order to examine the overall characteristics of the proposed algorithm, a simulation using PSIM software has been carried out and the informative results are displayed in Fig. 5 through Fig. 7. Fig. 5 shows sa, sb signal and estimated sc signal by the proposed method in this paper. And it is certified that the rotor information can be successfully obtained from only two optical sensors.

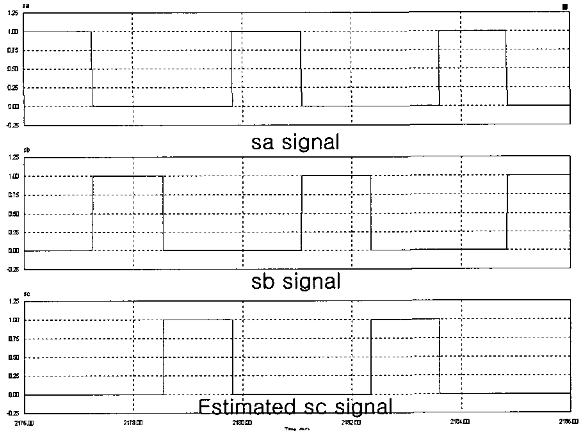


Fig. 5 sa, sb signal and estimated sc signal

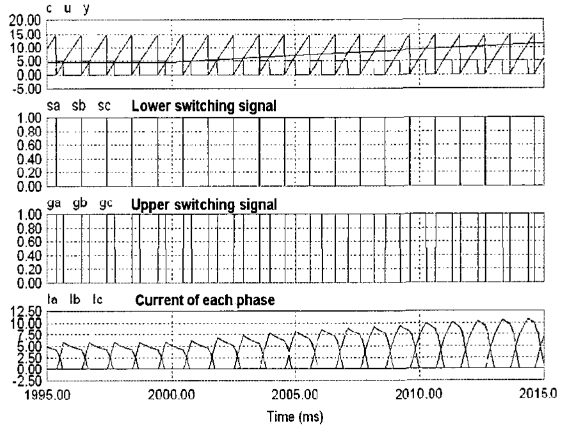


Fig. 6 Simulation waveforms

Fig. 6 shows the control signal 'u' and the duty of output 'y' when the reference speed value changed from 500[rpm] to 1000[rpm] after the start up. The output 'y' passes through 'sa', 'sb', 'sc', and AND circuit and it makes the upper switches signal of 'ga', 'gb' and 'gc'. The waveform at the bottom shows the rise of current to follow the rated speed as the duty of 'ga', 'gb' and 'gc' rises.

Fig. 7 shows the real speed and the current waveform of each phase corresponding to the reference speed when it is changed from 500[rpm] to 1000[rpm] after start-up.

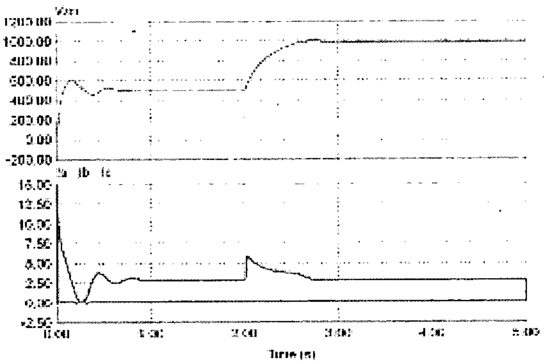


Fig. 7 Current and speed response of reference speed change

4. Experimental Results

Some experiments were carried out to verify the proposed method. The actual hardware prototype test bed, which is built in Sungkunkwan University.

Fig. 8 shows the block diagram of SRM drive system. In order to verify the performance of the control, a prototype drive was designed and developed as shown in the block diagram. A 160W SRM, rated 12V and 3,000rpm, is used and the detailed machine parameters are summarized in Table 2.

Table 2 Motor parameter

Rated power	160[W]	Phase resistance	0.0417[Ω]
Rated voltage	12[V]	Maximum inductance	2.33 [mH]
Number of phases	3[phase]	Minimum inductance	0.24 [mH]
Number of stator teeth	6[pole]	Number of rotor teeth	4[pole]

The estimated sc signal obtained from the proposed method in this paper, and the result is displayed in Fig. 9. Using only two optical sensors, the rotor position information can be provided at any instance. The 'sa' signal was used as the input of LM331 (f/V converter) to produce the output signal which is proportional to 'sa' pulse frequency to control the speed.

In Fig. 10, the signal 'u' is the error of the reference signal and the output signal in f/v converter. The signal 'c' is the saw-tooth pulse that occurs in the possible areas of

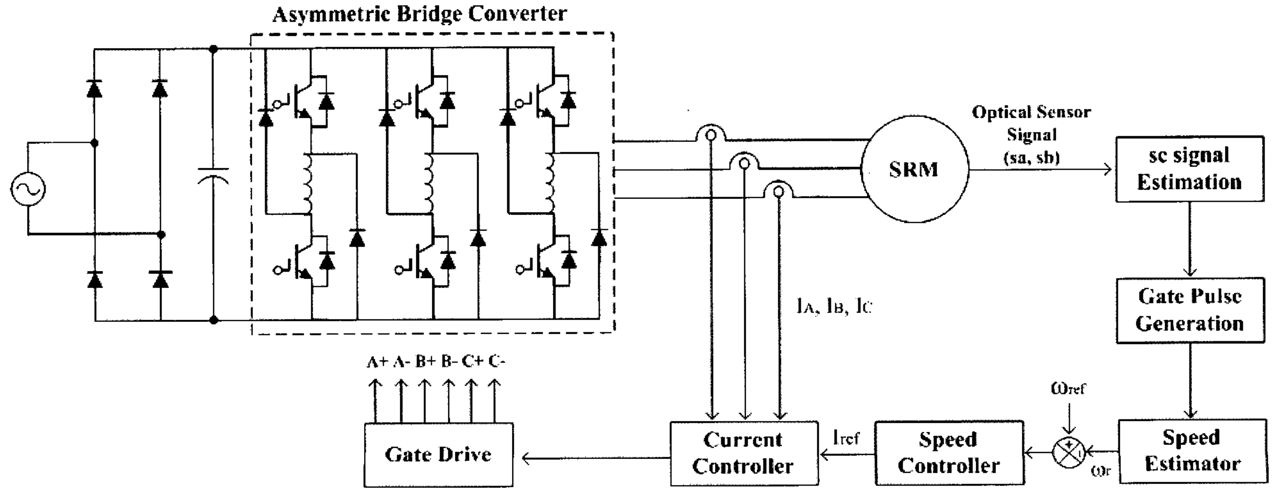


Fig. 8 Block diagram of SRM drive system

excitation at each phase. The signal 'u' and 'c' make the output signal 'y' through the comparator.

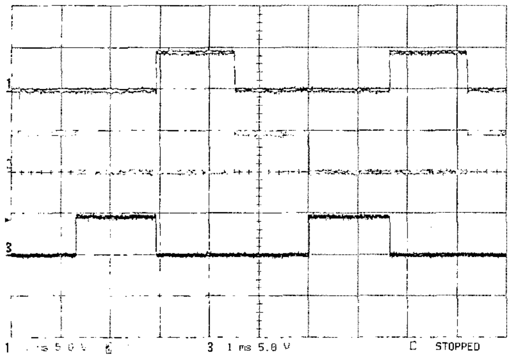


Fig. 9 sa, sb signal and estimated sc signal

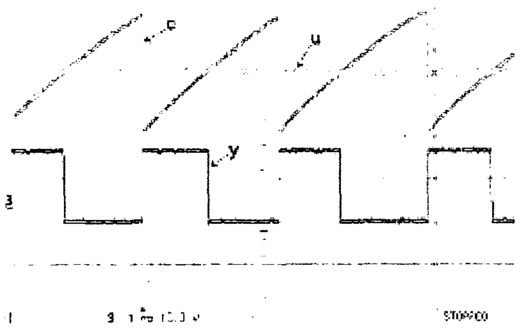


Fig. 10 Input and output waveform of comparator

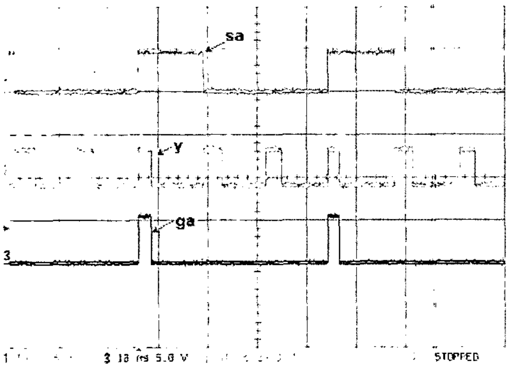


Fig. 11 Input and output waveform of AND circuit

Fig. 11 shows that the signal 'sa', 'y' and the signal 'ga' produced by the AND circuit with two signals. Signal 'ga' is used as an exciting signal at the upper switch of asymmetric bridge converter. The 'sa' signal exciting the lower switch and 'ga' signal exciting the upper switch of asymmetrical bridge converter make the soft switching method to reduce the torque ripple at low speed as well.

Switching duty can be decided by the signal of the error of speed reference signal and f/V converter signal (real-speed) in a comparison with saw-tooth waveform of each phase that has integrated 'sa', 'sb' and 'sc' signal. And then it goes into the AND circuit to determine the appropriate exciting time of each phase and controls the upper-switches of asymmetric bridge converter. By inputting the 'sa', 'sb' and 'sc' signal to lower-switches and changing the duty of upper-switches, we made freewheeling mode by the lower-switches and diode, when the upper-switches are off, to reduce the current and torque ripple.

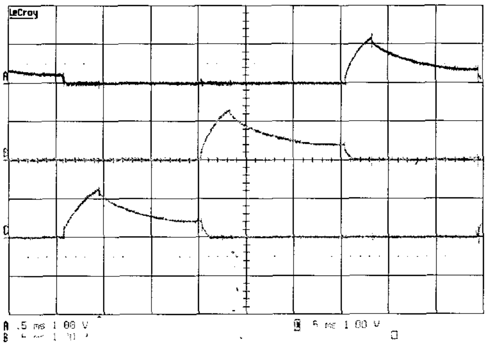


Fig. 12 Current waveform at forward direction (4A/div, 3500rpm)

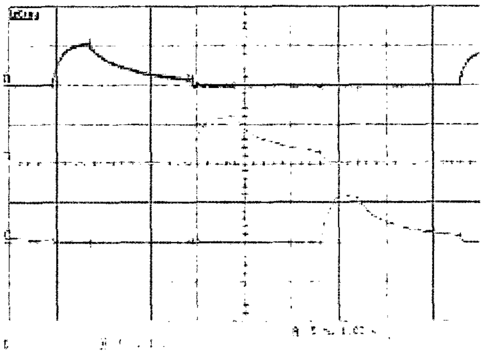


Fig. 13 Current waveform at reverse direction (4A/div, 35000)

Figs. 12 and 13 show the phase current waveform at 3,500[rpm] of forward and reverse direction by no-load. In order to demonstrate the speed dynamic response, the speed response characteristics is shown in Figs. 14 and 15 with the step change of reference speed.

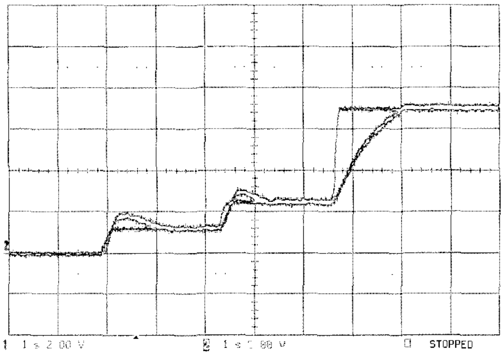


Fig. 14 Real speed when reference speed change (1sec/div, 800rpm/div)

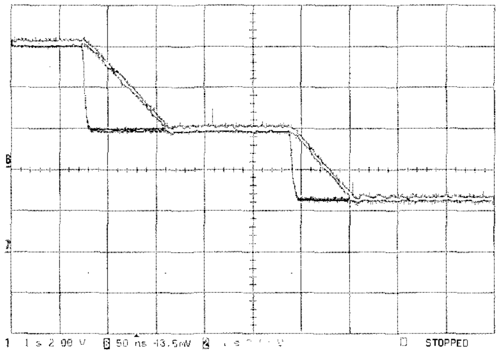


Fig. 15 Real speed when reference speed change (1sec/div, 800rpm/div)

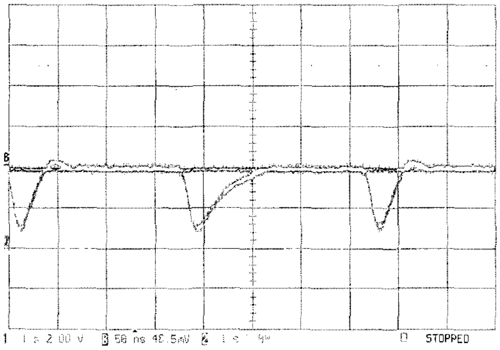


Fig. 16 Speed reversal test

The speed reversal test was also performed to verify the practicality of the proposed system. Fig. 16 shows the speed trajectory in both directions.

5. Conclusions

To operate SRM, the accurate position-information of rotor is necessary, so the expensive absolute-encoder, the resolver and incremental-encoder are needed for the rotor position information. However, it is not appropriate to use such high-cost position sensors in simple operating systems. In this paper, the optical-sensor technique was proposed, which improves the conventional method. The slotted-disk division is eliminated and the number of optical-sensors is reduced in the proposed method. Also the start-up operation is possible as well as forward and reverse operation.

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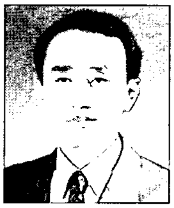

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