A New Sensorless Drive Method of Switched Reluctance Motors Based on Motor's Magnetic Characteristics

H. J. Guo, M. Takahashi, T. Watanabe, and O. Ichinokura

***Abstract*—We propose a new sensorless drive method of Switched Reluctance Motor (SRM) based on motor's magnetic characteristics. Some drawbacks of the method using impressed voltage pulse at unenergized phases to detect the magnetic characteristic have been improved. The proposed method has the features: only one unenergized phase has been injected by impressed voltage pulse, that simplifies both hardware and control algorithm, and a new idea to determining the injecting timing for impressed voltage pulse has been introduced, that extremely eliminates the negative torque caused by some residual currents. Because the proposed method is very simple, instead of expensive DSP, the entire experimental system has been implemented in an analog and digital circuit (FPGA: Field Programmable Gate Array).**

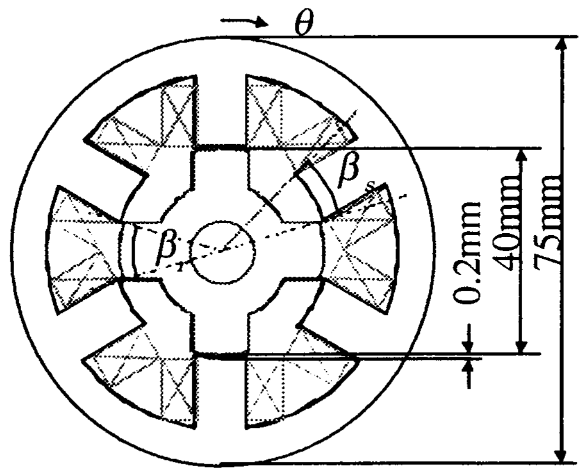
***Index Terms*—FPGA, inductance, position sensorless drives, switched reluctance motor.**

I. Introduction

SWITCHED Reluctance Motors (SRM) exhibit desirable features including simple construction, high reliability and low cost. It is useful to low-cost variable-speed drives in many industrial applications. However, SRM have not been put into practical applications widely because of its large torque ripple, acoustic noise and low power factor. In addition, a traditional position sensor is need for its control.

In recent years, sensorless drive methods have attracted much interest. The sensorless drive method using impressed voltage pulse (high frequency pulse) at unenergized phases is a simple and practical method [1]–[3]. This method focuses on the magnetic characteristic of SRM: the magnetic circuit of each phase changes with rotor positions. By injecting high frequency voltage pulse into unenergized phases, the related current pulses will change with rotor positions. Then, the exciting timing can be obtained by some thresholds which is set at the measured current pulse. But it has some drawbacks and has not been studied enough yet.

In this paper, we propose an improved sensorless drive method using the impressed voltage pulse technique. Two important improvements have been made: one is that instead of injecting the impressed voltage pulse into each phase, we only inject it into one unenergized phase that simplifies both hardware and control algorithm, the second is that a new injection timing of the impressed voltage pulse has been introduced. With these improvements, the negative torque caused from residue currents can be eliminated; the speed control range will be extended further. Experimental results confirm the proposed method is useful. Because the proposed method is simple, instead of using expensive Digital Signal Processor (DSP), the entire experimental system is implemented in a simple analog and digital circuit.



Core material	50H290
Stator pole arc. (β_s)	30 deg.
Rotor pole arc. (β_r)	32 deg.
Stack length	42mm
Winding/pole	28turns

Fig. 1. Structure of the SRM with parameters.

II. Proposed Method

A. Basic Characteristics of SRM

Fig. 1 is the schematic diagram of a six-stator pole, four-rotor pole, and three phases motor with stator windings. Fig. 2 shows the magnetic characteristics of the SRM. It is clear that the magnetic characteristics are nonlinear and position-dependent. This is the motivation for using impressed voltage pulses to detect the rotor position through related current pulses.

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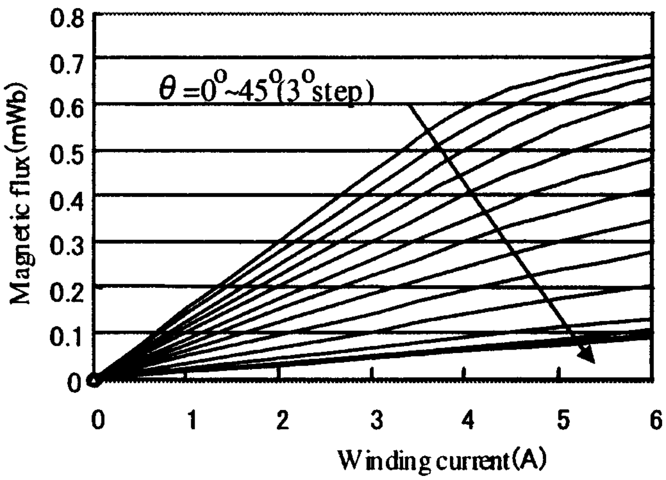

Fig. 2. Magnetic characteristics of the SRM.

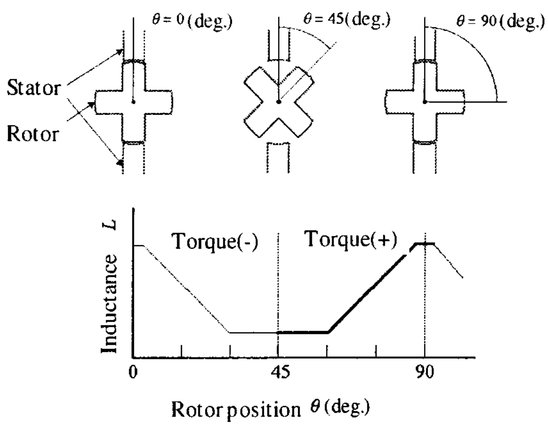

Fig. 3. Relation between rotor position and inductance.

For simple expression, using an approximate concept of inductance, the relation between inductance and the rotor position is shown at Fig. 3.

B. One Phase Injecting Method for Impressed Voltage Pulses

A conventional way is to inject the impressed voltage pulse at all phases of SRM, and set some appropriate thresholds to determine the exciting timing of the next phase, so similar circuit is needed in each phase. That causes the complication in both hardware and software.

To over come the drawback, we propose a method only using one phase for impressed voltage pulses. Figs. 4 and 5 show a simple image of the method. The main idea is that let the extracted current pulse (shown in Fig. 4) path through a low-path filter, then set some thresholds to determine the exciting timing of each phases as shown in Fig. 5. This method also has an advance way in noise resistance compared with using thresholds directly in the extracted current pulse.

C. Determining the Injecting Timing for Impressed Voltage Pulse

From the image of Fig. 3, in order to drive SRM efficiently, it is desire to avoid imposing any voltage at negative torque areas. The conventional injecting timing for impressed voltage pulses

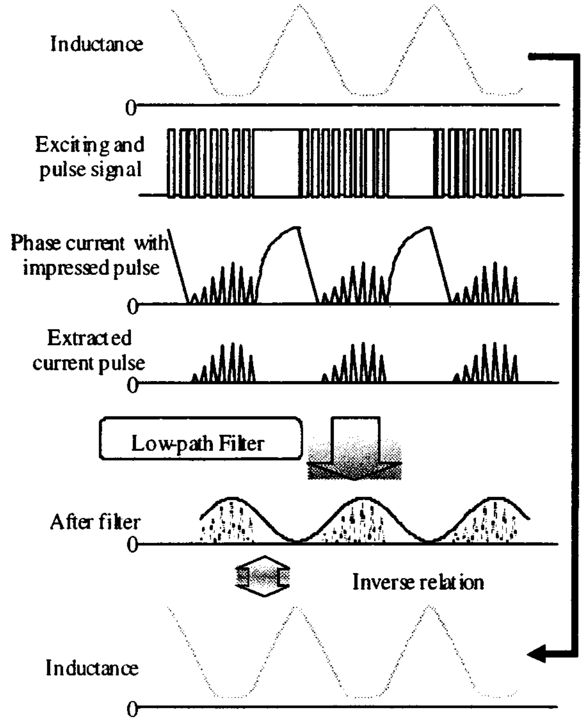

Fig. 4. Process to obtain a current pulse wave.

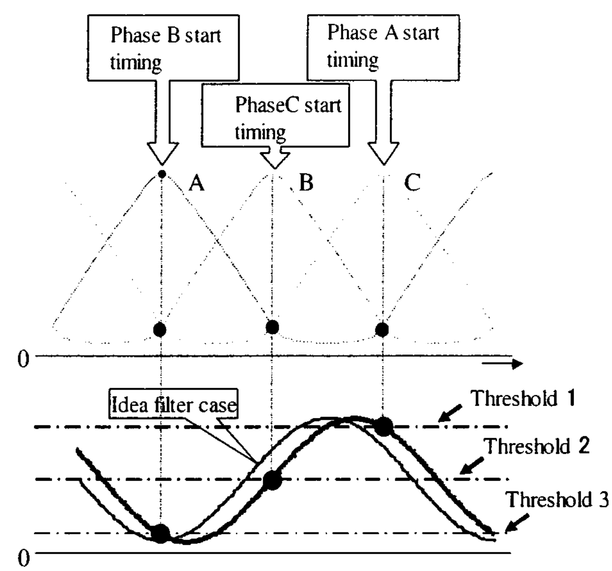

Fig. 5. Proposed method for determining exciting timing.

use the end of the exciting signal (see Fig. 6). It is clear that some impressed voltage pulses will be imposed at negative torque areas. When the exciting voltage is end, but some residual currents are still existence, impressed voltage pulses will last the existence of residue currents and bring more negative torque. This will affect the efficiency of SRM badly and prevent SRM from driving high speed.

Instead of using the exciting signal, we focus on the phase voltage signal shown in Fig. 6. It is clear that the negative end of the phase voltage and the end of the residual current is coincident. Using some circuit techniques to format the phase voltage as shown in Fig. 6, a new injecting timing for the impressed

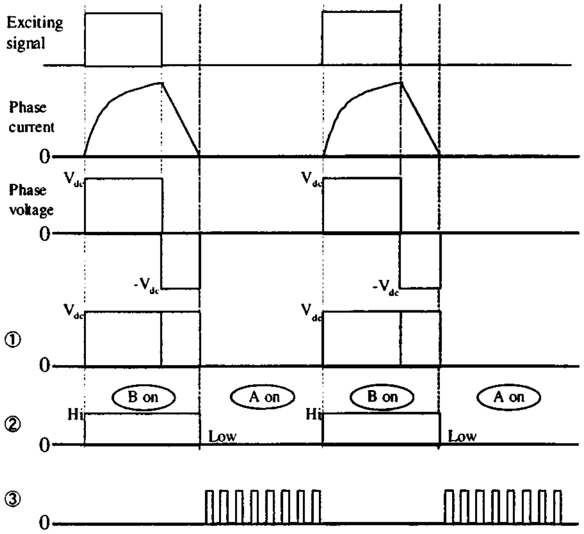

Fig. 6. Determination of injection timing for impressed voltage pulses.

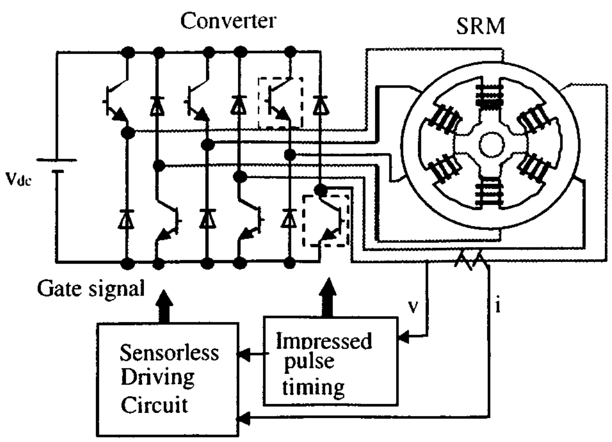

Fig. 7. Implementation of the experimental system.

voltage pulse has been introduced. With these improvements, the negative torque caused by residue currents can be eliminated extremely; the speed controllable range can be extended further.

III. Experimental Results

The experimental system is shown in Fig. 7. An asymmetric half bridge converter circuit is used to drive the SRM. We measure the voltage and the current of one phase to determine both the exciting timing for the driving and the injecting timing for impressed voltage pulses.

At the block of "Impressed pulse timing" in Fig. 7, the measured phase voltage is formatted as shown in Fig. 6 and the output is the impressed voltage pulses.

At the block of "Sensorless driving circuit," the measured phase current and the signal from the block of "Impressed pulse timing" are used to obtain the extracted current pulse just as shown in Fig. 4. Then pass it to a low-path filter, the exciting timing can be determined by three thresholds. Finally, D-flip-flop circuit is used to give the duration of the on-off time for each phase based on the exciting timing.

At the start point, a conventional starting circuit is used, and then shift to the sensorless drive. In order to focus on examining

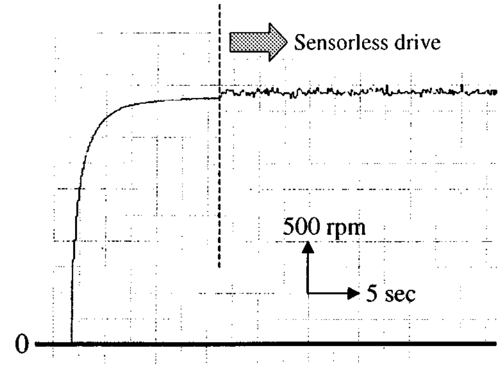

Fig. 8. Result of sensorless driving [6.2(V)].

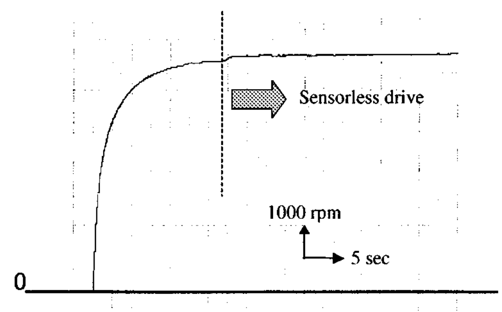

Fig. 9. Result of phase lead (3 deg.) exciting sensorless driving [10(V)].

the basic features of the proposed method and trying high speed driving, the experiments are under no load condition. The experimental result in Fig. 8 shows that the system is working well. Fig. 9 shows the SRM is rotating as high as 7000 (rpm). These have shown that the effect of the negative torque caused by conventional method has been eliminated extremely. The experimental results have verified our proposed method is useful.

IV. Conclusion

This paper has proposed a practical useful sensorless drive method of switched reluctance motor based on motor's magnetic characteristics. Through two important improvements, the speed driving rage has been put more wildly than so far. Because the proposed method is very simple, instead of expensive DSP, the entire experimental system is implemented in analog and digital circuits (FPGA). These techniques are expected to be important in applications where cost, size, and weight are primary concerns.

As a future work, we will extend the proposed method to construct anadjustable-speed control system.

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