Experiments in the Position Detection of Linear Switched Reluctance Motor

S.W. Zhao, N.C. Cheung, W.C. Gan and J.M. Yang

***Abstract*--Position detection is very important in operation of Linear Switched Reluctance Motors (LSRMs). With increasing application of LSRMs, the position detection techniques would get more and more attention. In this paper, a position detection scheme is proposed for LSRM. In the scheme, the position is estimated by the injection of a series of small current into phase winding and measurement of the increase of phase current. The preliminary experiments in position detection are performed on the proposed LSRM. The experimental results confirm that the scheme is effective for position detection of LSRM.**

***Index Terms*—Linear switched reluctance motor, position detection.**

I. INTRODUCTION

RECENTLY Linear Switched Reluctance Motors (LSRMs) have been obtained more attention for position or velocity control due to their low-cost and simple structures, ruggedness and reliability in harsh environments. Compared to the method of rotary motors with transformation components for producing linear motion, LSRMs also have many advantages, such as quickly response, high sensitivity and tracking capability, moreover, the structure of LSRMs can reduce the room requirement for its installation. According to the principles of LSRMs, the phase excitations of LSRMs need to be synchronization with the position for effective control. The mechanical sensors or optical encoders are usually used to obtain the position information. However, these sensors not only add complexity and cost to the system but also reduce the reliability of the drive system. The alternative to these sensors is indirect position detection based on measurements of other motor parameters.

Several methods of position estimation have been reported for Rotary Switched Reluctance Motors (RSRMs) [1-12] during the last two decades. Various position estimation methods can be mainly classified into the four groups.

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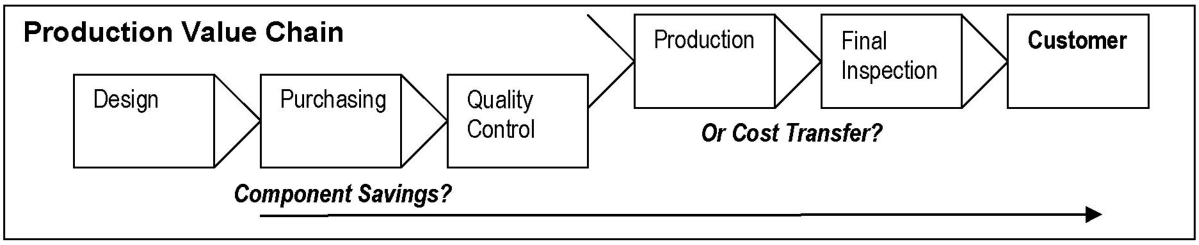
(a) Incremental inductance measurement-- The basic principle of incremental inductance was originally proposed in [1] and an analytical model of incremental inductance in term of Fourier series was reported in [2]. By investigating the chopping characteristics of phase current waveforms, this method mainly considers the relationship between incremental inductance and position.

(b) Flux linkage based estimation-- In paper [3], a non-intrusive rotor position estimation was proposed, which relies on the machine's inherent flux/current magnetic characteristics to infer rotor position from measurements of stator flux linkage and current during normal phase excitation. Considering the eddy effects, a correction factor was introduced [4]. And a principle of high resolution position estimation was proposed in [5], which uses either flux linkage or current to correct for errors in rotor position through correlation of current, flux linkage and rotor position.

(c) Methods of signal injection-- During the operation, there is at least one phase unexcited for a switched reluctance motor. Phase inductance can be estimated by injecting signals into the unexcited phase. A chopped current approaching to zero was proposed to inject to the unexcited phase [1]. Another group of this kind of methods is based on modulated frequency injection. By applying a small high frequency sinusoidal voltage to an idle phase, the phase inductance will be encoded in the amplitude and phase of the sensing current [6]. And a resonance based high frequency injection was proposed [7].

(d) Modern control theory based methods-- A state observer based on a nonlinear model of SRM with the state variables of flux linkage, speed and position was proposed in [8], a reduced-order extended Luenberger type nonlinear observer model along with the load torque was reported in [9, 10] an observer based sensorless with adaptive fuzzy controller was presented for switched reluctance motors. On the other hand, intelligent control based estimations such as neural networks are employed [11, 12].

However, for LSRM, there are few literatures referring to position estimation so far. RSRM and LSRM are similar in term of principle of operation; therefore, the position estimation methods for RSRM can be referred or applied on LSRM. But there are important differences with regard to position estimation. (a) Most RSRMs operate under speed control mode, while LSRMs are usually applied in position control and trajectory control.



When you consider all these costs, a company may be eroding profitability while they think they are improving it. Costs aren't being cut in purchasing, they are being transferred to the more expensive operations in the manufacturing processes. This assumes you discover a quality issue before the systems are built and shipped to the customer. If the problem occurs after the customer gets the system, that $500 savings will easily be buried under the cost of replacing defective parts and repairing a damaged customer relationship.

It is much easier for a company to measure the savings from buying cheaper components than the potential costs to operations of poor quality or late delivery, so companies measure the former and ignore the latter.

So the company is taking a gamble, and they don't know what it will cost you if they lose. This is what we call 'reverse roulette'. When you play regular roulette in Macau, you risk a known amount for a chance to win a larger known amount. The odds or success are evident and the greater the risk, the larger the winnings. In component gambling, you win a known amount up front (savings on the component), and assume the risk of losing a larger unknown amount later through production problems and customer dissatisfaction. If you later lose more than you saved, it was a bad gamble.

Most companies that play component roulette have no idea of the risks and the costs. Imagine standing at the roulette table in Macau and placing a bet without knowing how much you could lose. The dealer says, "I will give you $500, spin the wheel, and then we will know how much money you need to give back." You ask, "what are the odds I will have to give back over $500?" "Don't know," says the dealer, "it could be anywhere from zero to millions, let's spin the wheel and find out."

We can illustrate this point with a real-life example. Micrometals Inc. produces T106-52, which is an iron powder toroid that is one inch in diameter and costs $.10 (HK$.78).

Micrometals has been supplying this part to the industry for over 15 years and it was designed into a power supply used in a high-end server made by a well known computer company. A Micrometals competitor was willing to sell this part for $.08 (HK$.62) to get the business. The requirement was for 20,000 power supplies with two cores each. At 40,000 parts, this is a savings of $800, (HK$6,240) or 20% for the power supply manufacturer. However, this is only .02% savings of the cost of the power supply, and a .002% savings on each server.

The computer company was unaware of the power supply manufacturers change in core vendors and the substitute part was not equivalent in one important attribute; thermal aging. Micrometals products have superior thermal aging properties so they tolerate higher operation temperatures longer. The substitute vendor's cores were not evaluated in the original design and did not perform as well as the Micrometals cores. As a result they ran hotter. As they got hotter, the poor thermal aging properties made the parts even less efficient, so they ran hotter, and so on until component and power supply failure.

The servers that failed in the field had to be recalled and replaced. The computer manufacturer will receive over $1,000,000 in damages from the power supply manufacturer, which may not cover the intangible cost of lost future sales, insurance claims, distribution channel displeasure, and bad press.

Using our reverse roulette example, the power supply manufacturer took a chance on saving $800, but lost $1 million, plus an important customer. It was a bad gamble since the upside was very small compared to the down side.

In this particular case, the reason for the failure was discovered and the company making the gamble had to pay. Many times the cause is

$$v_j = r_j i_j + L_j \frac{di_j}{dt} \quad (3)$$

The phase inductance can be calculated by the ratio of current. It can be seen, for a given short period, that the increase of phase current varies with the inductance. Therefore, the position can be extracted by the measurement of the increase of the phase currents.

In real operation, the position can be obtained by the injection of a series of small currents into idle phase. And the current is so small that it can not almost produce force with the motor. Correspondingly, the drive circuit has two operation modes as driving mode and sensing mode. During the driving mode, the bottom switch is always closed while the top switch is operated with its duty cycle. In this way, the current ripple can be effectively reduced. During the sensing mode, both switches of the phase are operated with same actions. In this way, a series of small triangle current waveform can be injected into the phase winding quickly.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

According to the proposed position detection scheme, the increase of phase current would vary with the position when a series of small current waveform is injected into a phase winding. The experiment is carried out on the proposed LSRM. Fig. 3 shows the experimental results where the sensing current waveform varies with the position. From the figure, the increase of phase current is related to the position.

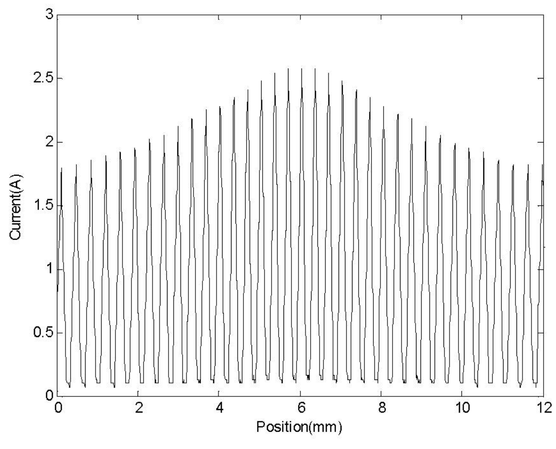


Fig. 3 The sensing current waveform with different positions.

For the sake of position detection, the relationship between the increase of phase current and position is required to be decided. Fig. 4 shows the characteristic curve for the position and increase of phase current. In the figure, the dots denote the actual measured increase of phase current at different positions and the solid curve is the fitted characteristic curve according to the measured data. From the following figure, the characteristic curve can fit the measured data accurately.

With the characteristic curve, the position can be easily detected by the measurement of increase of phase current. Fig. 5 shows the results of position estimation and actual position. In the figure, the speed is increased with time. It can be seen that the estimated position agrees with the actual position measured by the encoder and the estimated result is insensitive to the speed. Therefore, the experimental results validate that the proposed scheme is effective to the position detection for LSRM and the position can be accurately estimated by this scheme.

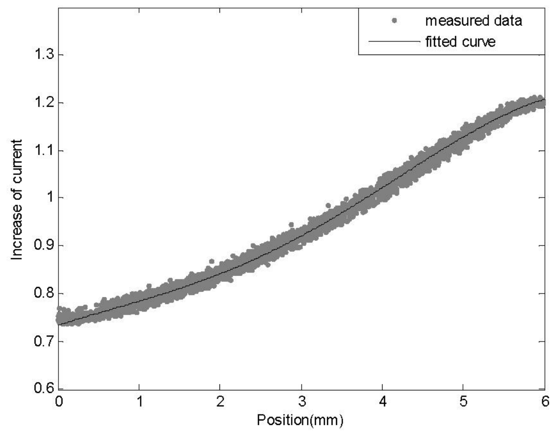


Fig. 4 The measured data for increase of phase current and the corresponding fitted characteristic curve.

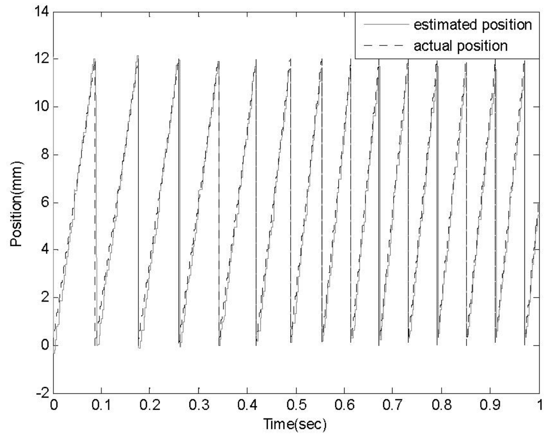


Fig. 5 Comparison between the estimated and actual positions.

In this paper, a position detection scheme is proposed for LSRM. In the scheme, the position is estimated by the injection of a series of small current into phase winding and measurement of the increase of phase current. The preliminary experiments in position detection are performed on the proposed LSRM. The experimental results confirm that the scheme is effective for position detection of LSRM.

V. ACKNOWLEDGMENT

The authors would like to thank the Honk Kong Polytechnic University for the funding support of this research work through project BQ831 and the general support of South China University of Technology through National Natural Science Foundation of China

(60674099).

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