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The Design of New Sensorless BLDCM Control System for Electric Vehicle

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Abstract

In order to meet the requirement of reliably running which is by Electric Vehicle for motor controller, the paper is focused on a sensorless brushless DC motor controller design and a commutation point method. By utilizing the saturation effect of stator iron core, six short voltage pulses are employed to estimate the initial rotor position. After that a series of voltage pulses are used to accelerate the motor. When the motor reaches a certain speed at which the back-electromotive force (EMF) method can be applied, the running state of the motor is smoothly switched at the moment determined by the relationship between the terminal voltage waveform and the commutation phases. "Lagging 90˚-α commutation" is bring forward to overcome the shortages existing in the traditional method. The experimental results verify the feasibility and validity of the proposed method.

Keywords: Brushless DC Motor, Electric Vehicle, Ensorless Control, Commutation Point

1. Introduction

Due to the advantages of high power density, robust structure, and ease of control, the brushless DC motor (BLDCM) has played an important role in many applications. It is necessary for high-performance applications, such as servos in machine tools and robotics, to use position sensors for successful starting and operation. The issues on reducing cost, low-performance applications, space-restricted applications, and reliability of the position sensors have motivated research on sensorless control [1-6]. In addition, the fast and continuing improvements of powerful and economical microprocessors and digital signal processors (DSPs) have speeded up the development of sensorless control technology. In fact, [7] enumerates many applications of the BLDCM, for example, air-conditioning compressor, engine cooling fan, fuel/water pump, electric vehicle.

The sensorless control technology of the brushless DC motor (BLDCM) based on the back-electromotive force (EMF) detection method has been widely used in the industrial and commercial fields. As we know, the magnitude of the back-EMF is proportional to the motor speed, so the back-EMF detection method cannot be applied properly when the motor is at standstill. In order to solve this problem, many methods have been developed. One of them, often referred to as a 3-step startup method, is used to align the rotor first in a predetermined direction, and then accelerate the motor in an open-loop scheme before the back-EMF method is applied. This startup method is easy to implement but it tends to be affected by the load and may temporarily cause reverse rotation which is not allowed in some applications.

In this paper, the short pulse sensing method, which is based on the saturation effect of the stator iron and will not cause any reverse rotation or vibration during the startup process. The key hardware implementation is the current sensor detected by Ri and the resistance network used as the voltage divider. The terminal voltage which reflects the back-EMF information is sampled by the A/D converter integrated in the micro-controller.

2. Initial Rotor Position Estimation

The phase inductance of the stator is determined by

$$L = \Phi \ / I \tag{1}$$

where I is the phase current and Φ is the flux due to magnet rotor and stator coils and core. **Figure 1** shows the inductance of stator windings with nonlinear magnetization characteristics of the stator core, depending upon the position of rotor. As the pole of magnet rotor is close to the stator winding, the ratio of the change of the current in the stator winding flowing in the magnetizing direction is larger than that in the opposite direction because of the magnetic saturation of the stator core. So the value of the current would be different according to the rotor position if a constant voltage vector from inverter is applied to the stator winding of the motor for a constant time period. The estimation of the rotor position is based on strongly magnetized stator field. Three situations of a magnetic pole of permanent magnet of the rotor close to the stator core are considered as shown in **Figure 2**. A smaller phase inductance L(sat) is defined when the stat- or field is in phase with rotor field, shown in **Figure 2(a)**. Similarly, a larger phase inductance L(linear) is defined when the stator field is out of phase with rotor field, shown in **Figure 2(b)**. **Figure 2(c)** depicts the case of middle value L(mid).

3. Initial Rotor Position Detection

Based on the operation principle mentioned above, six voltage pulses are injected into the phase windings and the peaks of the response current are compared with each other to determine the rotor position.

As shown in **Figure 3(a)**, the high-side power device VT1 and the low-side power device VT6 are activated first, which can be denoted as A+ B–. The resultant magnetic field is represented by arc line. Then the high-side power device VT3 and the low-side powerdeviceVT2 are activated, and are denoted as B+ C–, and arc line **Figure 3(b)** represents the resultant magnetic field. If the north pole of the rotor is in the same direction as that of the resultant magnetic field arc line and in the opposite direction from that of arc line, the peak of the response current is greater when the north pole of the rotor is in the

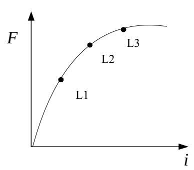


Figure 1. The inductance of stator windings with nonlinear magnetization characteristics of the stator core.

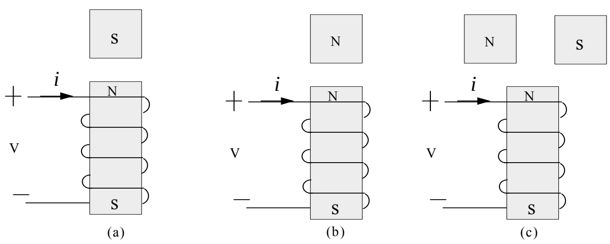


Figure 2. Magnetic fields (a) saturated magnetic field, (b) linear (non-saturated) magnetic field and (c) middle case.

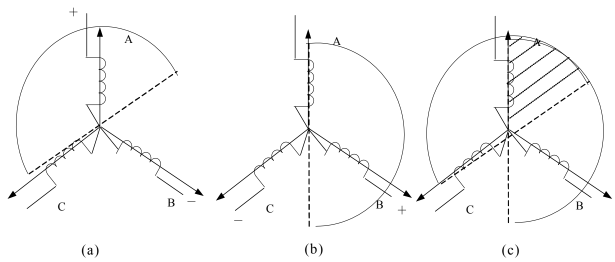


Figure 3. The schematic diagram of initial rotor position detetion. (a) Energized stator winding and rotor position within180°; (b) Rotor position within 60°.

same direction as that of the resultant magnetic field arc line and in the opposite direction from that of arc line, the peak of the response current is greater when the north pole of the rotor is in the same direction as that of the resultant magnetic field arc line. Thus the north pole of the rotor can be narrowed down to 60°, as shown in **Figure 3(c)**.

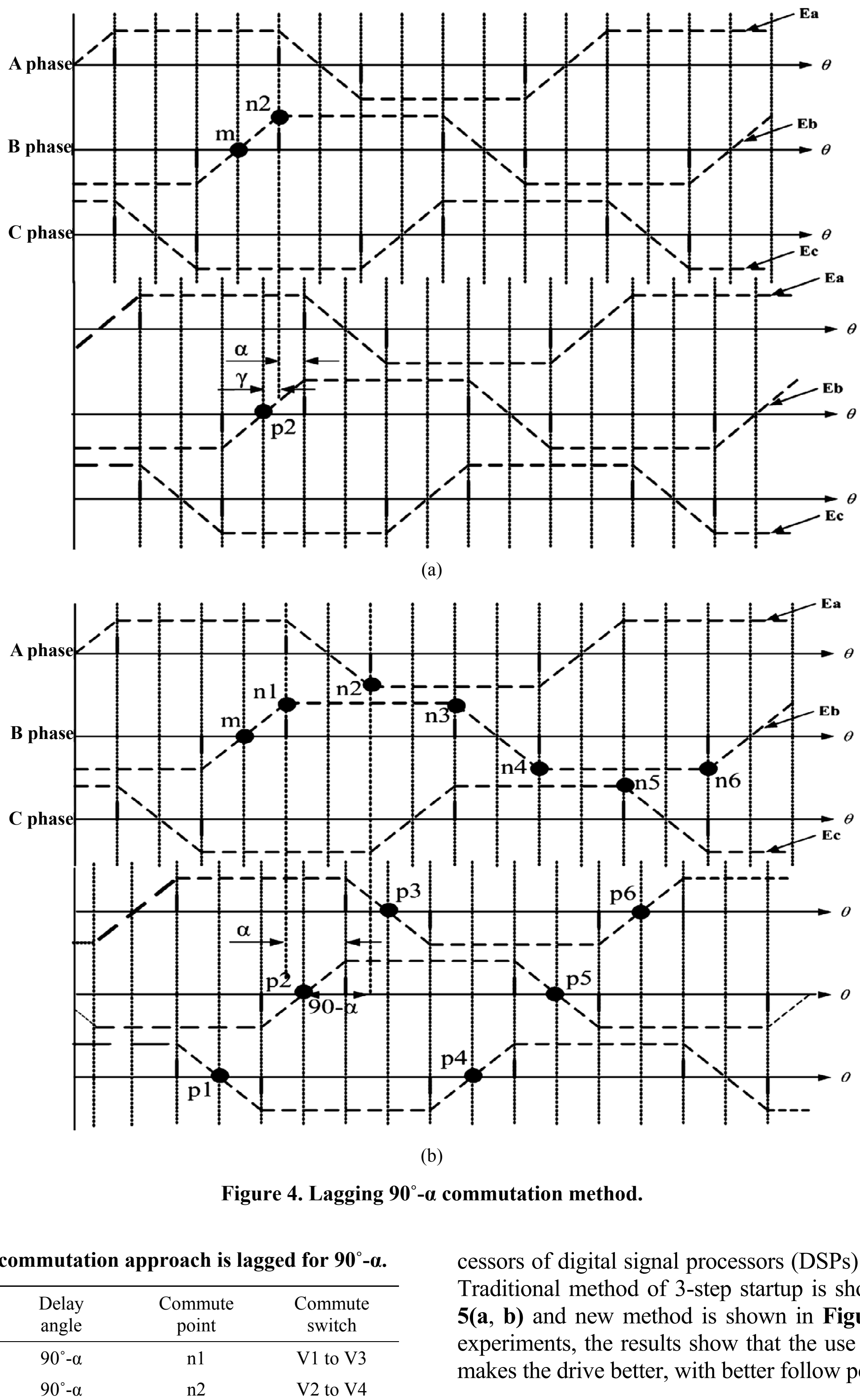
When the initial rotor position is identified, the motor is accelerated to a certain speed. Generally, a self-controlled BLDCM with trapezoidal BEMF waveforms is driven by a three-phase inverter with six-step commutation. Each conducting phase is called one step of two phase conducting. The conducting interval for each phase is 120° by electrical angle. Therefore, only two phases conduct current at any time, leaving the third phase floating. In order to produce maximum torque, the inverter should be commutated every 60°, and the commutations occur at 30° delay from the corresponding zero-crossing points (ZCP) of the BEMF waveforms.

4. Lagging 90˚-α Commutation Method

According to intensive analysis of the zero-crossing detection of Back EMF, a detecting method with band-bass filter is proposed. By analyzing the method in the detecting Back EMF, zero point of Back EMF is lagged, see **Figure 4(a)**, so the corresponding correction method and the new commutation approach are presented to improve the performance of the BLDCM, see **Figure 4(b)**. When detecting the zero-crossing of Back EMF, the commutation approach is lagged for 90˚-α, see **Table 1**. The position detection can be achieved over a wide speed range.

5. Experimental Results

The specifications of the test BLDCM are: 8 poles, 400 W. According to **Figure 3** for the initial position detection and based on **Table 1**, **Figure 5** display the response of velocity waveform. To verify the proposed method, we conducted some experiments. In experiment, the currents are sampled to verify the rotor position, the key hard ware of the current sensor and powerful micropro-



(a)

(b)

Figure 4. Lagging 90˚-α commutation method.

Table 1. The commutation approach is lagged for 90˚-α.

zero-crossing point	Delay angle	Commute point	Commute switch
P1	90˚-α	n1	V1 to V3
P2	90˚-α	n2	V2 to V4
P3	90˚-α	n3	V3 to V5
P4	90˚-α	n4	V4 to V6
P5	90˚-α	n5	V5 to V1
P6	90˚-α	n6	V6 to V2

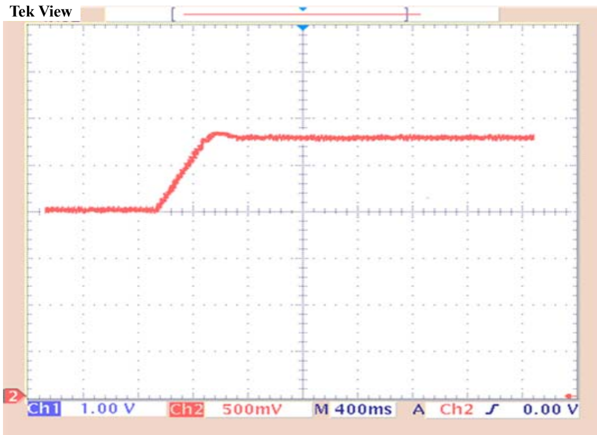
cessors of digital signal processors (DSPs) should be used Traditional method of 3-step startup is shown in **Figures 5(a**, **b)** and new method is shown in **Figure 5(c)**. In the experiments, the results show that the use of the methods makes the drive better, with better follow performance.

6. Conclusions

In this paper, new startup and smooth switching method of a sensorless brushless DC motor is presented. By us-

(a)

(b)



(c)

Figure 5. Speed response curve.

ing this method, the rotor position at standstill can be estimated with a resolution of 60° and the motor is accelerated to a certain speed at which the back-EMF detection method can be applied. The method will not cause any reverse rotation or vibration during the startup process. The hardware implementation of the driving circuit is simple. It is very suitable to use in the low-cost applications.

7. References

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