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Design of Brushless Direct Current Motor Control System Based on DSP

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Abstract. As the energy and environment crises become more and more intense, people are becoming more and more conscious of environment protection and energy conservation. Electrical vehicles are gradually being accepted and becoming the development trend for vehicles, which are characterized by free pollution，low noise, high energy efficiency and simple structure compared with traditional internal combustion engine automobile vehicles. In selecting the driving motor of electric vehicle, the brushless DC motor is favored by many auto dealers with its advanced features. As a result, based on motor's mathematical model and controlling theory, this paper started from the basic structure and working mechanism of brushless DC motor, to build the simulation model based on Matlab/ Simulink platform control system, which mainly includes speed and current regulation module, logic commutation module, dual-mode converter module, motor module, overlapping commutation module, and three-phase full-bridge inverse module. Then, the simulation results are obtained to provide references for the subsequent design of hardware circuit and software programs. Besides, the overall scheme of control system is determined by taking performance indexes into consideration, and the circuit design for the system hardware based on DSP2812 is completed, which mainly includes central processing unit, main power circuit, driving circuit, detection circuit, dual-mode switching circuit, display circuit, speed adjustment circuit, power supply circuit and reset circuit, of which the working principle and functions are presented in this study.

1. Introduction

With the continuous intensification of atmospheric issues and energy issues, people's awareness of environmental protection and energy conservation are increasing constantly, and more and more attention has been paid to the issue of automobile exhaust emissions. With more stringent requirements put forward for emission standards, many researchers have participated in the pollution-free research on new energy vehicles. [1] As a typical representative of new energy vehicles, the electric vehicle is a kind of high-tech industry that integrates automotive technology, computer technology control technology, power electronics technology, electrochemical technology, and new energy technology, which is the future development trend of automobiles.

Electric vehicles mainly include hybrid vehicles, pure electric vehicles, and fuel vehicles. The main difference between the three different types of electric vehicles is the use of different energy and power systems [2]. Most hybrid vehicles use fuel and electric energy as their energy sources, of which power systems are composed of fuel engines and electric motors, and each power ratio is allocated through the control system to achieve coordinated, efficient, and stable operation. The pure electric vehicles use electric energy as energy source and motors as power systems; the fuel vehicles use fuel cells as energy sources and motors as power systems. The electric vehicles are equipped with many

advantages compared with the traditional internal combustion engine cars: no pollution and low noise, high energy efficiency, simple structure, and easy maintenance. It can be seen that the development of electric vehicles is the trend of the future of the automotive industry, which is also an inevitable requirement to replace traditional automobiles [3]. However, the current development of electric vehicles is still not perfect. Improving the cost-effectiveness, safety and cruising range of electric vehicles is an urgent problem to be solved, which are also essential factors in accelerating the popularity of electric vehicles.

Electric vehicles are usually composed of a body, a drive motor system, a battery management system and different control systems. As the core part of an electric vehicle, the drive motor and its control system not only determine the overall performance of the electric vehicle, but also distinguish it from fuel cars. The drive motor for electric vehicles is different from common applications and requires not only safety and reliability, but also stable performance. In addition, it has stricter and stricter requirements in terms of low speed, high torque, wide speed range, high power and small size, and large overload capacity. The government and automobile manufacturers have invested a lot of manpower and financial resources to develop and produce electric vehicle power drive systems [4]. The brushless DC motor not only has the advantages of simple structure and reliable operation of the AC motor, but also has the advantages of the good mechanical properties of DC motors, which are the development direction of future electric motors.

The brushless DC motor is a typical electromechanical integration product, which replaces brushes and commutators with its own position sensor to complete the real-time commutation during the operation of the motor. As a kind of universal new type speed governor with high performance and simple control structure, the brushless DC motor is widely used [5].

This paper uses a brushless DC motor as the driving motor of the micro electric vehicle. According to the system performance index, the purpose of this study is to use the DSP2812 as the core to design a brushless DC motor controller for electric vehicles. The background and significance of this study is firstly analyzed; based on the basic theory of brushless DC motor control system, then the system simulation model is established using MATLAB; finally, according to the system design requirements, the system hardware design is completed.

2. Basic Theory of Brushless DC Motor and Control System

The development of brushless DC motors has undergone the following stages in general: (1) Analog Circuit: According to the system's task, a large number of discrete components are connected to achieve the motor commutation, motor drive and speed control and other functions, which is characterized by good real-time. However, its structure is complex, and its reliability and scalability are also poor, making it difficult to implement complex algorithms. (2) Application-specific integrated circuits: with the development of power electronics, many companies have also introduced its own dedicated motor control chips of brushless DC motors, such as MC33035, TB6537B, etc. Most of these chips can be used to compose modular hybrid control systems. The reliability of this circuit is greatly enhanced, and it can meet the application in basic situations, but its intelligence and scalability are poor, which still limits the large-scale application [6]. (3) The microcontroller: the 8-bit or 16-bit microcontrollers are used as its core, combined with some discrete components or application-specific integrated circuits, to form a control system with high control accuracy, strong adaptability, and implementation of complex algorithms. It satisfies the application in most occasions, but due to its complex structure, low computing speed, and poor real-time performance, its applications in high-precision and high-speed occasions are restricted. (4) DSP: the company TI introduces a variety of DSP chips such as DSP24 series, DSP28 series in order to meet the motor control requirements, which adhere to the advantages of MCU, and integrate multiple motor control dedicated modules, which enhances processing speed greatly and can meet the application requirements of motor in high speed and high precision.

2.1. Basic structure of brushless DC motor system

In general, the definition of brushless DC motors in the academia is presented as follows: only the brushless DC motors with trapezoidal or square-wave back-EMF waveforms can be referred to as brushless DC motors, while the brushless motor with back-EMF is sine-wave cannot be called brushless DC motor, which is called permanent magnet synchronous motor [7]. According to the definition, the brushless DC motor is a self-controlled inverter-type synchronous rotary motor, which can be regarded as an electromechanical integrated control system consisting of a power electronic commutation circuit, a position sensor and a motor body. The specific structure of brushless DC motor is shown in Figure 1.
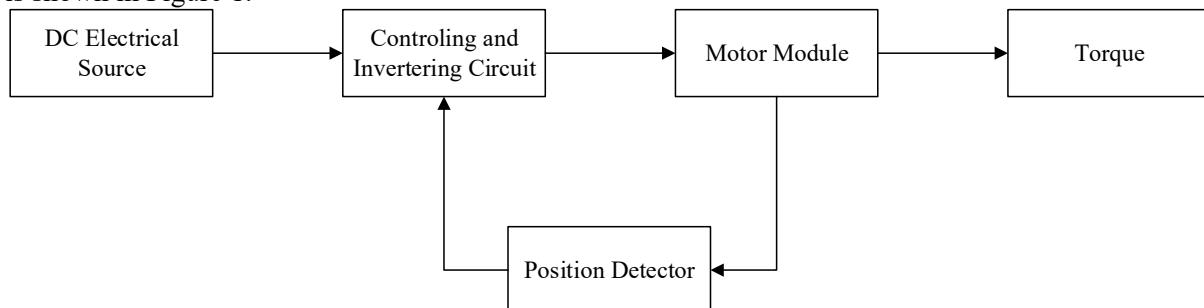

Figure 1. Brushless DC motor system

2.2. Working principle of brushless DC motor

In this study, the three-phase brushless DC motor operating in a three-phase, six-state, two-two-conduction mode is taken an example a to illustrate the working principle of brushless DC motor, which is shown in Figure 2. Assuming that the pole pair number of the motor is P=1, and the windings are star-connected.

When the rotor is in the position (0°) as shown in the left of Figure 3, the Z, B, and X phase bands are below the magnetic pole of N pole, and the C, Y, and A phase bands are below the S pole: based on the rotor position of sensor, the output signals make the VT1 and VT6 tubes conducted. The current flows from the positive electrode through the VT1 tube into the AB winding and returns to the negative electrode through the VT6 tube. At this point, the stator and rotor magnetic fields are interacted with each other, causing the rotor of the motor to rotate clockwise. After turning 60° electrical angle, the rotor position is shown in the right figure of Figure 3. In order to avoid inconsistent current directions of some of the conductors in the armature windings under the same magnetic pole, when the rotor is turned to the position of the right figure of Fig 3, it must be phase-inverted so that phase B is de-energized and A is positively energized.
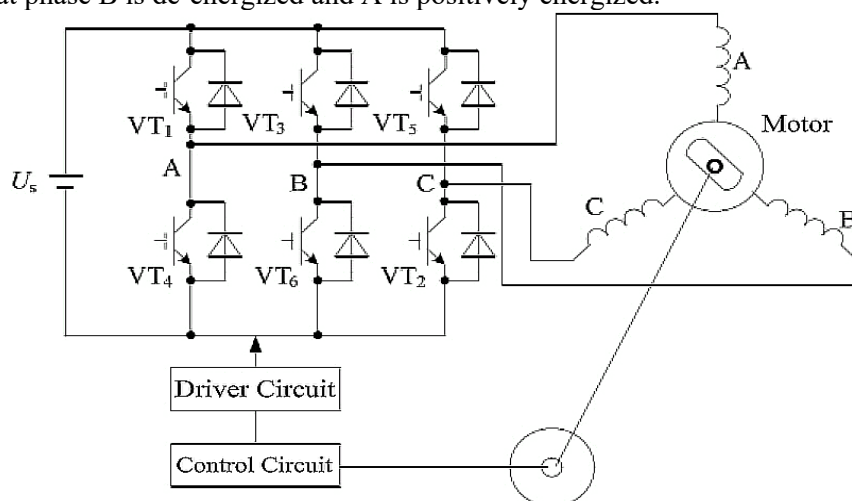

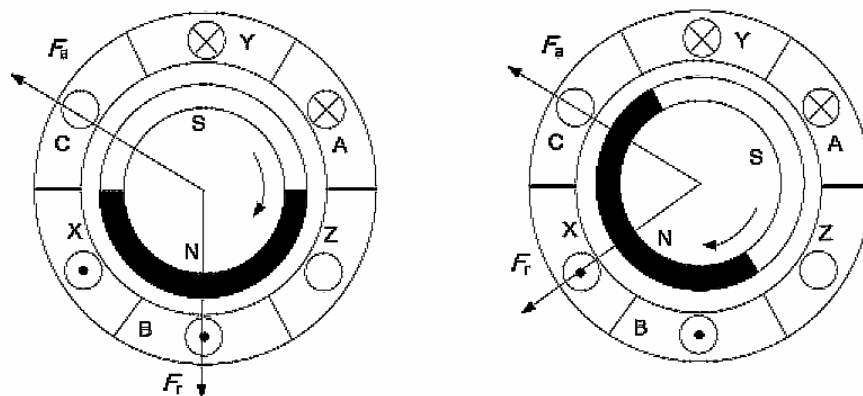Figure 2. Three-phase brushless DC motor control system

Figure 3. Brushless DC motor working principle

3. Brushless DC Motor Control System for Electric Vehicles
According to the characteristics of the electric vehicle drive system and the basic theory of the brushless DC motor, this system uses a permanent magnet brushless DC motor as the electric vehicle drive motor. Combining the mathematical model of the brushless DC motor and the basic theory of motor control, the overall design of the brushless DC motor control system for electric vehicles and the establishment of the simulation model are completed, which provides reference for the subsequent hardware design.

3.1. Control Scheme Determination
According to the performance requirements of the brushless DC motor controller [8], the control scheme is selected next. For electric vehicles, the vehicle speed needs to be changed at any time, and the amplitude of speed change is relatively large. Therefore, the higher requirements on the adjustment of the motor speed are put forwarded by controller; when the electric vehicle carries a heavier object or performs climbing operation, the brushless DC motor's operating current will increase accordingly. Therefore, the higher requirements on the adjustment of the motor current are also imposed by controller. Considering the rpm (revolutions per minute) and current regulation functions, a double closed loop control system where the outer ring is the speed loop and the inner loop is the current loop is used in this study.

The speed loop can eliminate the speed deviation and achieve the constant speed function. When the motor is started, the current regulator outputs the maximum current due to the saturation phenomenon of the speed regulator to speed up the transition process and ensure the rapid start of the motor. When the motor is overloaded or even blocked, the output of the excessive current is limited, which plays protective role and ensures the safe operation of electric vehicles. The PI regulator is widely used for the speed and current regulators, which has the advantages of convenient implementation, good control performance and convenient parameter setting, etc., and therefore it is widely used in various control systems. However, the traditional PI controllers cannot play the biggest advantage in the multi-coupling and nonlinear system like brushless motor. As a result, the method of fuzzy PI control combined with fuzzy control and PI control are adopted in the speed control loop of this system. In summary, the brushless DC motor control system for electric vehicles adopts a dual closed-loop control scheme of a fuzzy PI speed loop and a classic PI current loop. Considering the torque ripple suppression of dual-mode conversion and overlap commutation, the overall control scheme of the system is determined as Figure 4 shows.
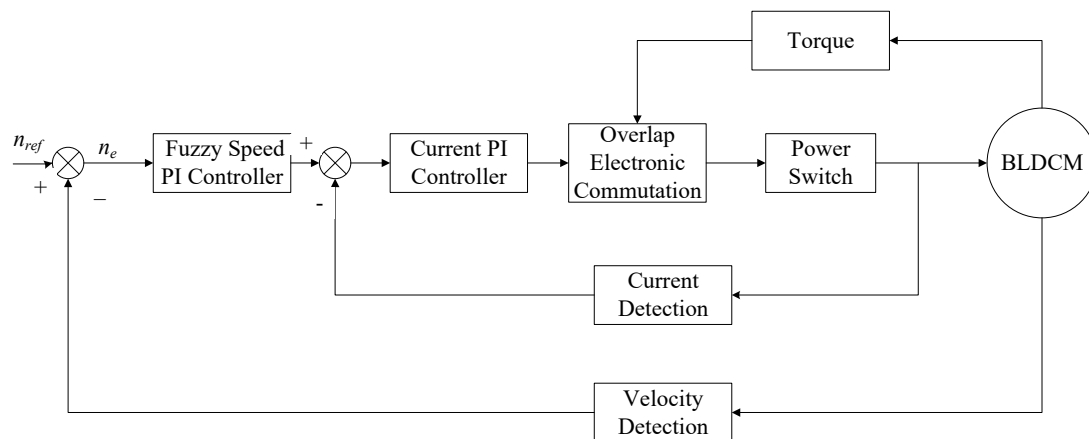
Figure 4. Double closed-loop control system for motor

3.2. Control System Model Establishment

According to the basic block diagram of the brushless DC motor control system and the basic theory of the motor control system, the entire control system simulation model is established based on the Matlab/ Simulink platform, and the subsystem packaging technology is used to achieve the modular design.
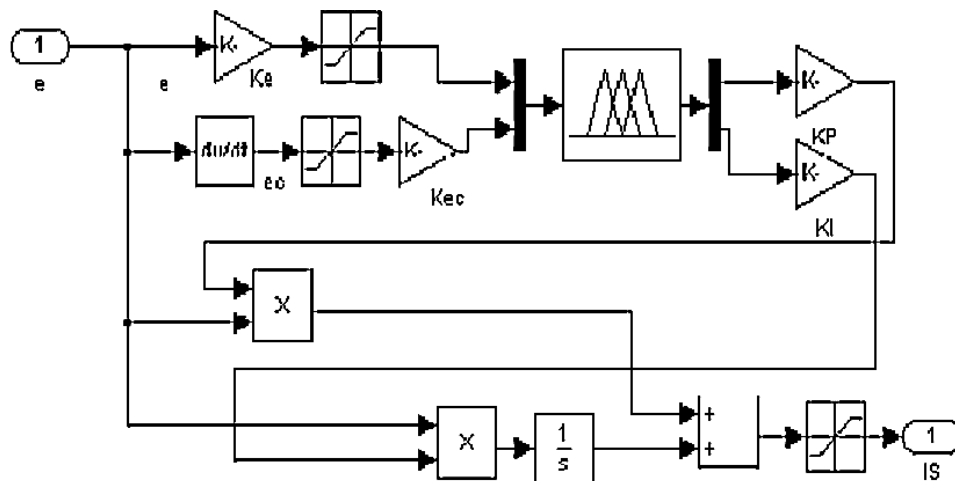

Figure 5. RPM (Revolutions Per Minute) Fuzzy PI Module

According to the basic theory of fuzzy control and the fuzzy controller design method, the classic PI model and the fuzzy control model are combined to establish an adaptive fuzzy PI controller to achieve online adjustment of PI parameters. In this study, the two-dimensional fuzzy controller is used as the speed fuzzy PI module, the speed deviation E and speed deviation change rate EC are selected as input signals, and the coefficients of Kp and Ki are selected as output signals. According to control system performance index speed adjustment range of 0-3000 r/min, the speed deviation actual domain range is set by [-3000, 3000]. According to the input and output quantization intervals, membership functions, fuzzy control rules, fuzzy inference methods and defuzzification methods, the FIS system files and the rpm fuzzy PI control module are established, which is shown in Figure 5. Based on thermo fuzzy PI module, the output surfaces of Kp and Ki are obtained as shown in Figure 6 a) and b) respectively.

a)   Output surface of the K_p b)   Output surface of the K_i
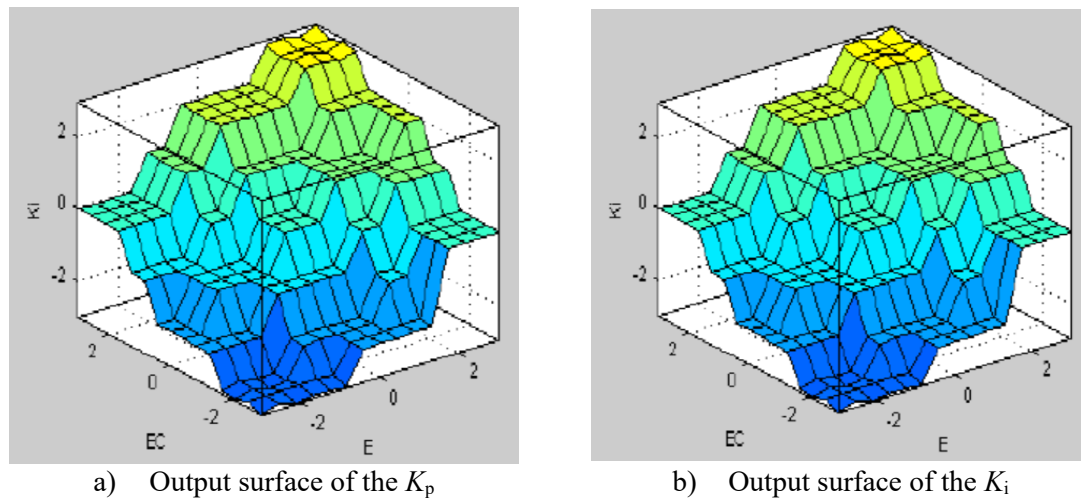
Figure 6. Output surface of the Kp and Ki

3.3. Brushless DC Motor Control System Hardware Design for Electric Vehicles
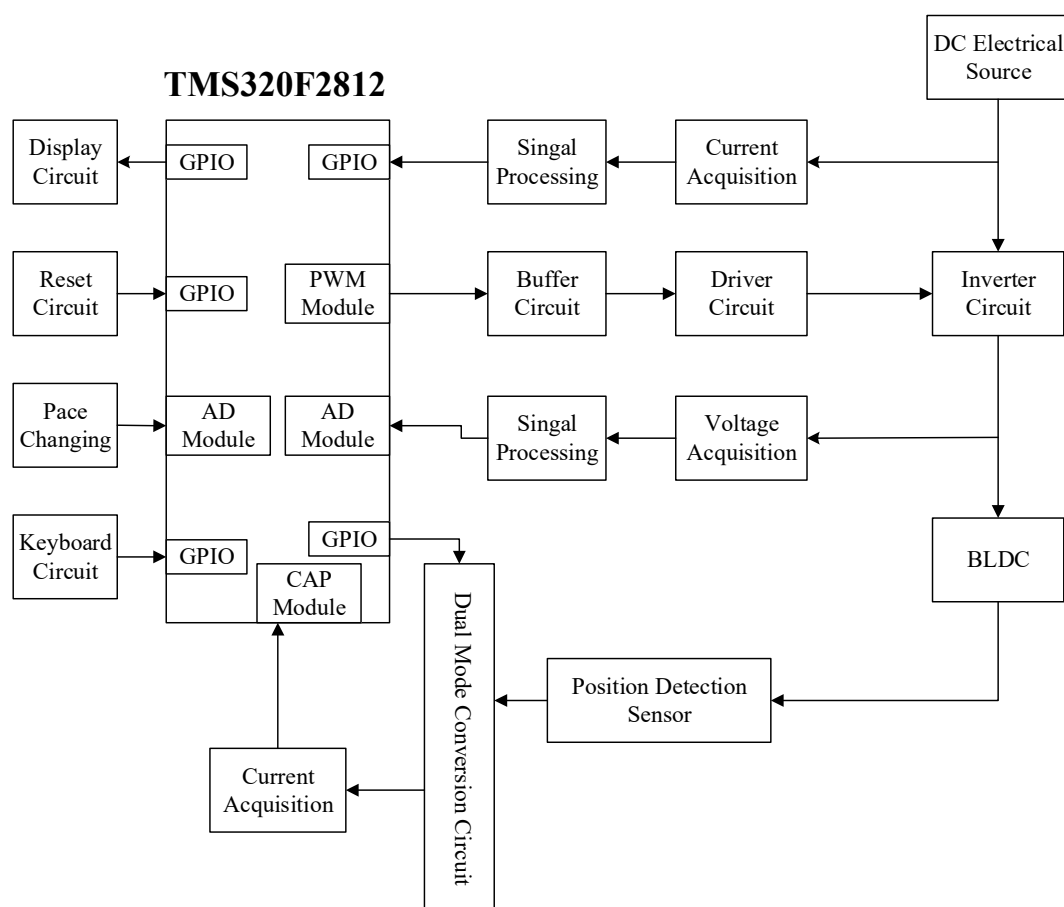

Figure 7. The Block Diagram of Hardware System

According to the performance indicators of the brushless DC motor controller for electric vehicles, the hardware design of the brushless DC motor control system is completed, of which the specific

structure is shown in Figure 7. The entire system is powered by a DC power supply, that is, a vehicle battery, which is used to convert DC current into a square-wave current available for a brushless DC motor through an inverter bridge. The phase sensor or position sensorless detection circuit are used to complete the commutation energization of the winding to maintain the motor operation. Based on the keyboard and display circuit, the system parameters are set to display current, voltage and other parameters in real-time. The TMS320F2812 chip is adopted as the central processor of the entire system to complete system logic adjustment and various data processing. Once the system program runs away or the system is powered on, the reset circuit will work to ensure the system reliability.

4. Conclusion
The development of electric vehicles is the trend of the future social automobile industry, which generally includes four major components, and the drive motor with its control system directly determine the overall characteristics of electric vehicles. In this paper, the brushless DC motor fuzzy control system for electric vehicles is taken as the research object, and the methods of theoretical analysis combined with system simulation are used to accomplish the following tasks. Firstly, based on the brushless DC motor and its control theory, combined with the mathematical model of the brushless DC motor and the performance indicators of the control system, the simulation model is established based on the Matlab/Simulink platform, and the double closed loop of the current PI and the speed fuzzy PI is built. Then, the overall control scheme of the system is determined, and the brushless DC motor control system hardware design based on the DSP2812 is completed. The design principles and implementation functions of each unit are described in detail. The electric vehicles will occupy an important position in the future market, and the vehicle controllers powered by brushless DC motors are determined to have good development prospects. Therefore, this study is equipped with good reference value and practical significance for the future application of brushless DC motor electric vehicles.

Acknowledgement

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