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Speed Adjustment for Brushless DC Motors Using Microcontrollers

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***Abstract:* Brushless DC motors have many advantages so that they are widely used. Because there are no mechanical reversing parts using brush rings so this BLDC motor overcomes most of the disadvantages of common DC motors. Hence, in order to adjust the speed for this motor, we use microcontrollers to improve the quality of the system**

***Keywords:* Brushless DC Motor, Microchip Dspic Microcontroller, Hall, Control, Speed Adjustment.**

Symbols	***Unit***	***Meaning***
R_a, R_b, R_c	Om	Stator Phase Resistances
V_a, V_b, V_c	Voltage	Phase Voltages
L_a, L_b, L_c	H	Stator Phase Inductors
i_a, i_b, i_c	A	Stator Phase Currents
M_{ab}, M_{ac}, M_{ba}, M_{bc}, M_{cb}, M_{ca}	H	Mutual Inductance Among Phases
e_a, e_b, e_c	V	Electromotive Force of Phases a, b, c
ω_r	Rad/s	Speed of Rotor
T_e, T_L	N.m	Electric Torque and Torque Load

Abbreviations

BLDC BLDC-Brushless DC Motor

I. Introduction

The brushless DC motor (BLDC) has no mechanical reversing parts using brush rings so this BLDC motor overcomes most of the disadvantages of common DC motors. This motor has high efficiency due to reduced power loss, no maintenance and small rotor inertia.

Automated systems using traditional electric motors are often designed with relatively inexpensive similar elements. The weaknesses of the similar systems are life expectancy of components and they are sensitive to changes in temperature. Another drawback of these systems is that it is difficult to expand and upgrade. Numerical control structures overcome all the disadvantages of the similar drive structures. High-speed digital signal processors allow the implementation of numerical control problems that require high resolution, high speed and large volume. In addition, they also allow the minimum delay time in the control loop. These high-performance controls also allow to reduce torque fluctuation and power loss. Continuous waveforms allow optimization of power elements and input filters.

In the article we use a Microchip Dspic microcontroller to adjust the speed of a brushless DC motor.

II. The Speed-Adjusting Experimental System For BLDC Motors

The connected blocks on the experimental table are like in Figure 1: The experimental object is a brushless DC motor. Speed response when changing the speed setting value from 30rad/s to 25rad/s after 3s and then changing again to 30rad/s, speed response when adjusting the regulator parameter. To adjust the speed we use the PSPIC33FJ64MC506 microcontroller to control the switching of valves of IGBT set. To determine the position of the rotor we use Hall sensors.

Fig.2 The experimental table of the control system: connected to the computer and results shown on the oscilloscope.

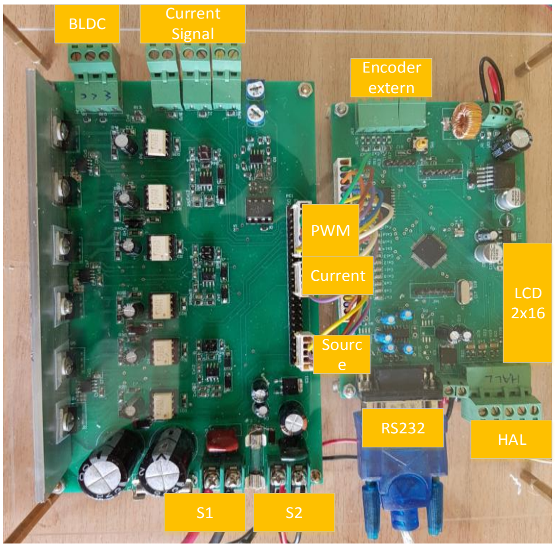

Fig.1. Connected Blocks on an Experimental Table

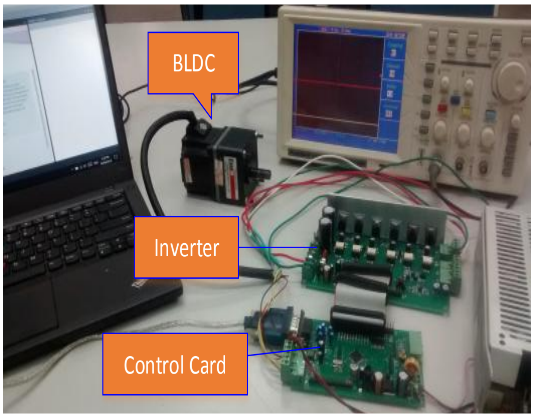

Fig. 2. The Experimental Table of BLDC Control System

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III. Overview Of A Brushless Dc Motor, Algorithm Model And Method Of BLDC Motor Control

The structure of a brushless DC motor is very similar to a permanent stimulation synchronous AC motor with a permanent magnet. The basic difference of a brushless DC motor compared to a permanent stimulation synchronous AC motor is that it combines some means to determine the position of the rotor (or the position of the magnetic pole) to create electronic switch control signals. Therefore, the brushless DC motor is a combination of a permanent stimulation synchronous AC motor and an electronic reversing switch according to rotor positions. The position of the rotor is determined via position sensors. Most of the rotor position sensors (magnetic poles) are Hall elements, but there are also some motors using optical sensors.

Almost all brushless DC motors have Hall sensors hidden inside the stator, in the rear axle (auxiliary shaft) of the engine. Whenever the rotor's magnet poles pass through the area near the Hall sensors, the sensors send out high or low signals when the North or South pole go past the sensor. Based on the combination of signals from three Hall sensors, the exact switching order is determined.

In order for the BLDC motor to work, it is necessary to know the exact position of the rotor to control the process of switching off the semiconductor locks, powering the stator coils in a proper sequence. The torque is generated by the interaction of the magnetic field generated by the stator coils with the permanent magnet. To keep the motor rotating, the magnetic field produced by stator coils must rotate synchronously with the rotor's magnetic field at an angle α.

Algorithm Model and Control Method:

1. Algorithm Model of Brushless DC Motors:

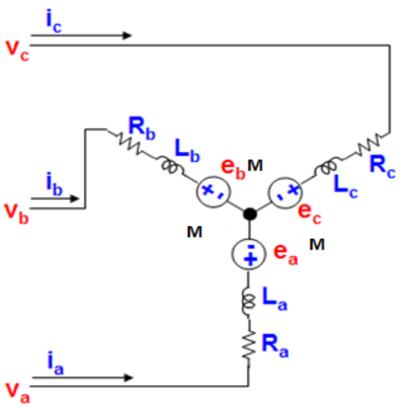

Fig. 3. Equivalent Circuit Diagram of BLDC

Voltage equation on coils:

$$v_a = Ri_a + (L - M)\frac{di_a}{dt} + e_a$$

$$v_b = Ri_b + (L - M)\frac{di_b}{dt} + e_b$$

$$v_c = Ri_c + (L - M)\frac{di_c}{dt} + e_c$$

V_a, V_b, V_c: are phase voltages a, b and c.

$R_a = R_b = R_c = R$: are stator resistors of phases a, b and c.

$L_a = L_b = L_c = L$: are stator inductances of phases a, b and c.

i_a, i_b, i_c are stator currents of phases a, b and c.

$M_{ab} = M_{ac} = M_{ba} = M_{bc} = M_{cb} = M_{ca} = M$ are the inductance between phases.

e_a, e_b, e_c are the dynamic rates of phases a, b, c.

The electromagnetic torque of the motor is calculated through mechanical power and electrical power. Because the friction in the motor is mainly produced between the motor shaft and the bearing, this friction force is small. In addition, the engine fabrication material is also a type with high resistivity so it can be assumed that iron losses and copper losses are neglected. Therefore, the power input to the motor is also equal to the mechanical power on the axis end.

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{w_r}$$

Mechanical equation

$$T_e = B_m w_r + J_m \frac{d}{dt} w_r + T_L$$

ω_r is the mechanical speed of the rotor, T_e is the electromagnetic torque, T_L is the load torque and J_m is the inertial force.

2. Control Method:

The control model for a contactless DC motor and how to implement it. Especially the simulation of PWM converter is done by switching functions.

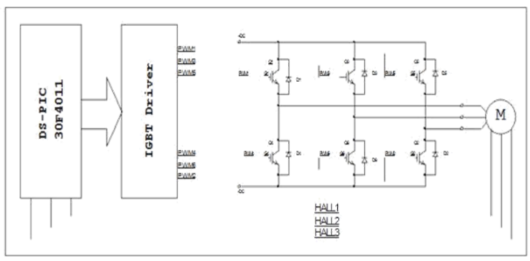

Fig. 4. Brushless DC Motor Control System

Figure 4 is the power circuit structure of the change system to control 3-phase BLDC motors.

To control the BLDC motor, we control the switching of the corresponding valves through pulse width modulation. The pulse width modulation is performed by Microprocessor: DSPI 33 FJ64MC506_I / PT

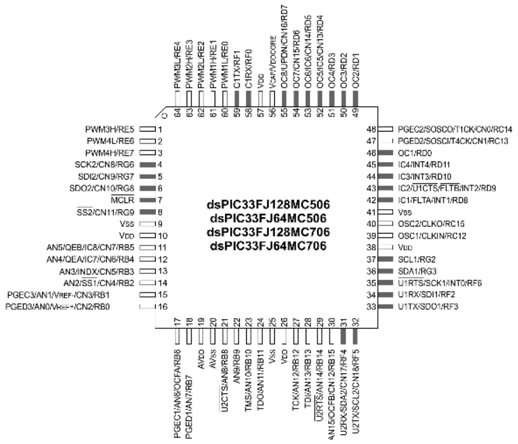

Fig. 5. Microcontroller Components DSPIC33FJ64MC506

Using DSPI microprocessor as the main controller, generating PWM pulses for buffers, the microcontroller must perform the task of getting the signals from the HALL sensors.

Modulation method of PWM: the control structure consists of 2 layers, the inner one is the current control loop, the outer one is the speed control loop:

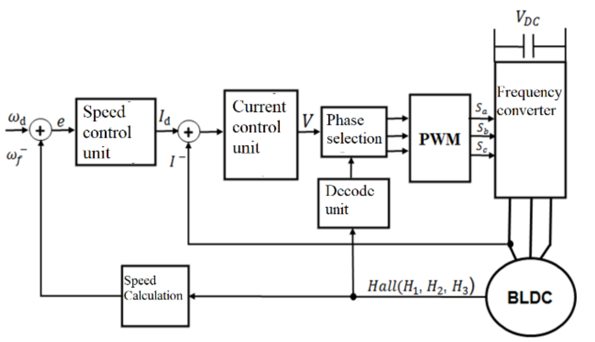

Fig. 6. The Proposed Controller Structure Diagram for BLDC

From that we have a single-phase replacement diagram:

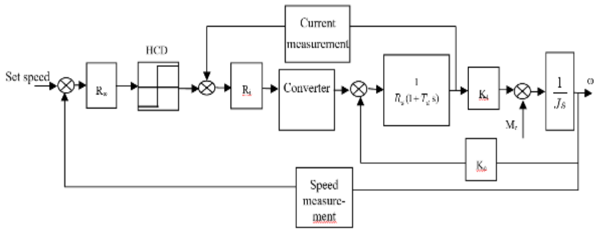

Fig. 7. The Converter is Represented by the Transfer Function:

$$W_{bd} = \frac{K_{bd}}{(1+sT_{bd})} = \frac{4.8}{1+0.001s}$$

$$K_{bd} = \frac{U_{cd\max}}{U_{dk\max}} = \frac{24}{5}$$

Select $T_{bd} = 0.001$

Synthesis f Current Circuit Loop:

Due to the high power motor, we can ignore the change of dynamic reaction E in a short time, so we can simplify the current control loop circuit as follows:

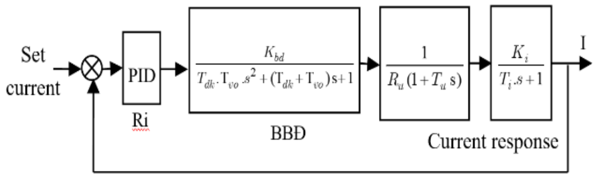

Fig. 8. The Minimal Current Loop Circuit Model of BLDC Motors

Applying the optimal standard of the module for the above object, we have the current regulator as PI block. The current regulator will look like this:

$$R_i = \frac{1+T.s}{K.T.s}$$

Inside: and $T = T_u$

Replace the number we have:

$$R_i = \frac{1+0.03s}{0.01s}$$

Synthesis of Speed Loop:

When synthesizing the speed loop, the current loop is replaced by the standard function and ignoring the influence of dynamic reaction and torque of resistance because in a small time the components change slowly.

The time constant T_s is small, so we can ignore the component s2 in the denominator of the standard function to facilitate the synthesis. Then we have the model of speed loop circuit as follows:

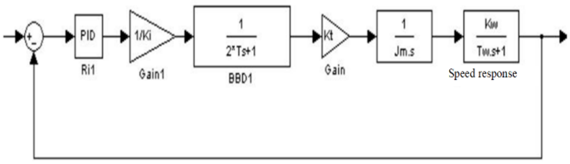

Fig. 9. Model of Speed Loop Circuit of Motors

$$W_{dt} = \frac{K_t K_\omega}{K_i(1+2sT_s)(1+sT_\omega)(sJ_m)}$$

Applying the symmetrical optimal standard for the above object, the speed regulator is as follows:

$$R_\omega = \frac{T_c}{2KT_s'} \cdot \frac{1+4T_s'}{4T_s's}$$

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IV. SIMULATION RESULTS

The BLDC motor with the following parameters:

Prated = 60W; p = 4; R_s = 2.08Ω; L = 5.5 mH; J = 0.00019 kg.m^2;

Simulating the layer control algorithms for brushless DC motors with feedback current DC-link.

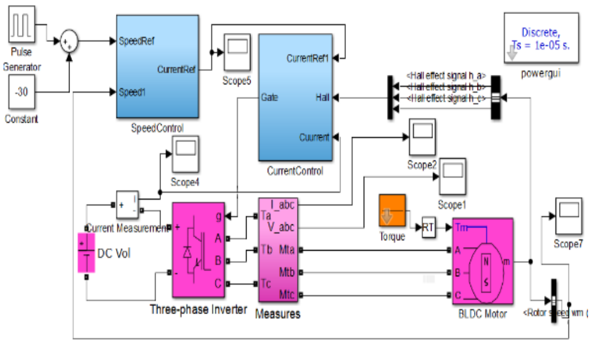

Fig.10. Simulation Diagram Implemented on MATLAB - Simulink

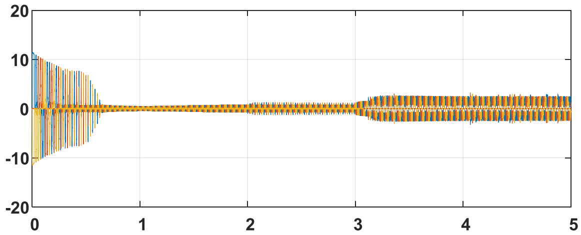

Fig. 11. Phase Currents of the BLDC Motor

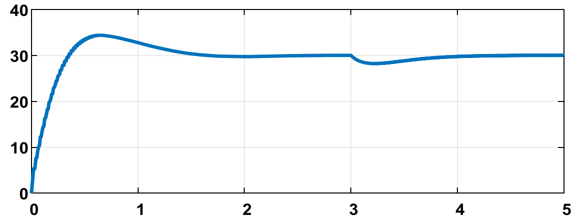

Fig. 12. Speed Response when Loading

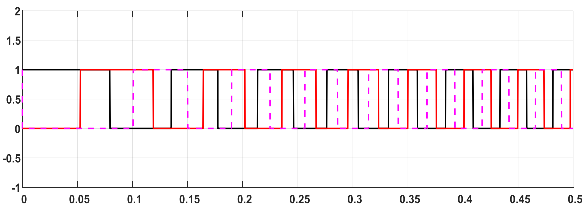

Fig. 13. Signal from Hall Sensors

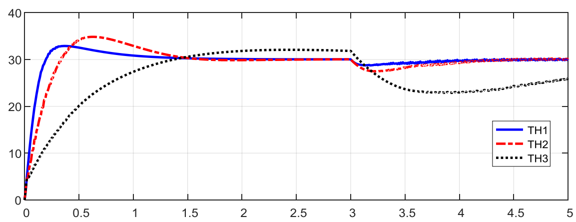

Fig. 14. Speed Response when Changing Parameters of the Regulator 1, 2, 3

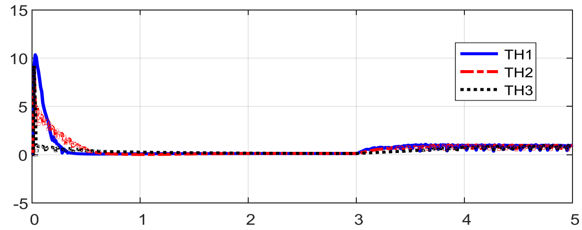

Fig. 15. Current Response when Changing Parameters of the Regulator 1, 2, 3

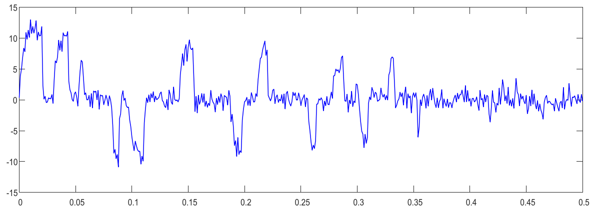

Fig. 16. The Form of Phase a Current when Experimenting

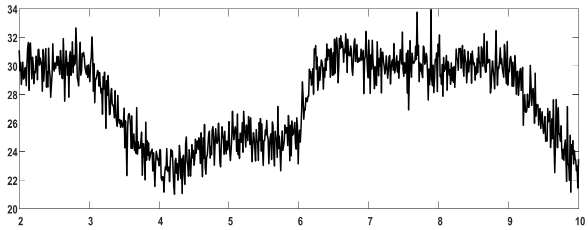

Fig. 17. Speed Response when Performing Experiments

From simulation results and experiments, we see that the proposed controller performs well the task of maintaining the set speed and stability under the condition of load disturbance.

V. CONCLUSION

When using the microcontroller to control the BLDC motor, the system has met the requirements. Besides, the layer control algorithm with the inner layer controlling the current, the outer layer controlling the speed also brings stable results, responding to different cases of the set values in both simulations and experiments.

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