A Rapid Development Method on Brushless DC motor Controller

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Abstract—**A rapid development method on Brushless DC motor (BLDCM) controller is proposed in this paper. It is founded upon a platform based on common actuated circuit and software MATLAB, which is called PACM for short. Its hardware is a common actuated circuit founded on dSPACE. And its software is a type of model architecture which built by introducing modularized modeling tool MATLAB/Simulink, and is compatible with various controlling algorithms. According to the rapid development method, the necessary hardware design and controlling software codes can be gotten rapidly. Experiments validate the convenience and the efficiency when using this rapid development method to develop the algorithm for a certain treadmill controller. Compared with traditional ways, it shortens the development cycle remarkably and reduces the development cost.**

Index Terms: **Brushless DC Motor (BLDCM); Rapid Development; Controller model architecture**

I. Introduction

In industrial application, BLDCM has been paid more and more attention due to its compact structure, high reliability and large output torque. [1]With it widely expending in application field, the developing requirement of motor control system becomes stricter, not only in dynamic and static performance of the system and control precision, but also in reduction of development cycle and cost. All of these requirements enormously increase the difficulty of development. On the other hand, with the progress of hardware technology, for example, DSP, embedded system and FPGA have been wildly used in control field, some intricate and intellectualized control algorithms could be adopted, especially when controlled objects are nonlinear, the AI-based control algorithm is even more effective.[2] For instance, fuzzy control, neural network control and etc.[3] But these complicated algorithms demand much more encoding and debugging time, which determine total system development cycle and cost.

The tradition development process of BLDCM controller is to establish the scheme of whole system firstly, according to the target control performance, then hardware is manufactured and software is encoded. The last step is to evaluate the control performance of the system in real work environment. If it cannot satisfy the requirement, the hardware and software will be modified until they pass the evaluation. . Currently, the hardware structure of brushless DC motor controller is technically mature and nothing remains but to select a kind of hardware structure in several candidates. Comparatively, the variety of control algorithms costs much more time in encoding and debugging. Considering the performance price ratio, the purpose of BLDCM controller's development contains two parts. The first one is to achieve the target of control performance, which means to fulfill the force moment, control precision, acceleration and deceleration time, and so on; and another one is to reduce the development cost. That means reduce both cost and time. This causes it must be selected out the best collocation of hardware structure and software algorithmic within the shortest time. This development process is difficult to carry out in traditional ways.

According to normal BLDCM controller's structures and features, this article introduces a platform based on common actuated circuit and software MATLAB (PACM). It is a platform to realize different algorithms conveniently and efficiently. A common actuated circuit based on dSPACE real-time simulation system is the PACM's hardware. With the help of modeling tool MATLAB/Simulink, we constructed the PACM's software model architecture through bridging Simulink and dSPACE hardware platform seamlessly. We used real-time control tool ControlDesk to achieve control algorithm's online analysis, debugging and verification. By using PACM, we had got a common development method on BLDCM controller. Finally, in this way, we controlled a real BLDCM with PACM, got relevant hardware structure and control code, and accomplished the controller's development.

II. The PACM's hardware ------ common actuated circuit based on DSPACE platform

The type of dSPACE system we used is single board system DS1104. It could actualize intercommunion with PC through PCI slots. Its specific application is to deal with complicated high speed digital signal processing and real-time simulation. Based on TMS320F240DSP, it contains Slave-DSP subsystem used as the supplement of general I/O ports.[4] Because of the dSPACE platform's I/O ports are standard TTL signal ports, its A/D and D/A ports can only handle signals whose voltages are between -10V and +10V, and the whole summation dSPACE's I/O current intensity cannot exceed 500mA.

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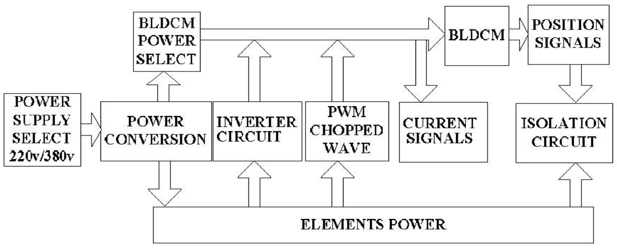

Fig. 1 Actuated circuit structure

Therefore it is unable to be used for BLDCM's controlling directly. An actuated platform is added into the system to drive motor, and at the same time it can protect dSPACE platform.

According to the operating demand of BLDCM, we designed an actuated circuit shown in Fig.1. It adopts current and speed closed loops principle. The actuated circuit can support the trio phase BLDCM's driving motion whose power is below 3000W.

In digital circuit part ,we used Slave-DSP PWM module to control the major loop's PWM chopped wave, applied Slave-DSP Bit I/O module to master multiple-path inverter circuit ,and used ADC Unit module to sample current signals and position signals. At last, the dSPACE platform communicates with PC by RTI. For dSPACE systems, Real-Time Interface (RTI/RTI-MP) carries out a linking function. Together with Real-Time Workshop from the Math Works it automatically generates real-time code from Simulink models and implements this code on dSPACE real-time hardware. It accomplishes C code's automatic generation, compilation, link, downloading and execution. [5] In addition, RTI generates a variable file of signals and parameters, which can be accessed and modulated by dSPACE's experiment tool ControlDesk. [6]

III. THE PACM'S SOFTWARE MODEL ARCHITECTURE

According to closed-loop control principle, the PACM's software model architecture consists of position feedback, current feedback, actual speed calculation, phase shift Logic, target speed set and control algorithm module. The relationship of them is shown in Fig.2.

In Fig.3, it is the ultimate module of every part, which is carried out by Simulink. Based on modular concept, when a different algorithm is adopted, we do nothing but change the inner control algorithm model in Control Policy module, for example, PID control model, fuzzy control model and neural network.[7][8] We can establish parallel selection widget to let diversified control algorithm coexist. When it works, we choose a control model we need by ControlDesk.

When controlled object is different, in order to guarantee model's versatility, we need to adopt congruent connecting type of hardware circuit, and make some change on parameter settings of basic control modules.

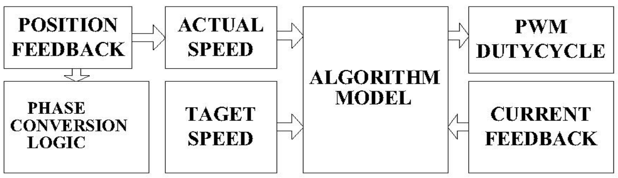

Fig. 2 The model's structure

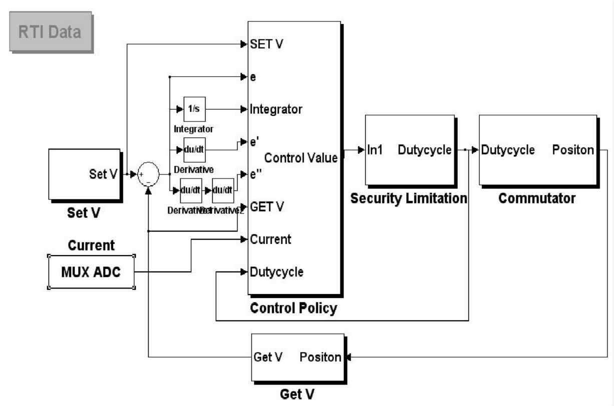

Fig. 3 Controller model architecture

Because of low installation accuracy of BLDCM's position transducer, it is possible to appear big velocity dithering, when the speed is only sampled by the time between two adjacent positions. This might expend the system resources greatly. Thus, the method of average velocity is popular in practical control. In Fig.4 (a) velocity sampling module, the parameter Rotate Number means the cyclometer number during average velocity calculation. In the picture, it expresses that velocity calculation carries out every 4 circles.

In order to solve the diversity of phase numbers, progressions and position transducer numbers, we need a parameter Count Cycle .Its formula is shown below.

$$Count\ Cycle = 2 \times Rotate\ Number \times Progression \tag{1}$$

In consideration of difference of the final expression of velocity, for instance: n/min, rad/s, and so on; so the step size of dSPACE's equation solver could be chosen differently. We use a parameter Timerate to implement the transition of different speed expression.

In phase shift module, as is shown in Fig.4 (b), we can achieve natural phase shift control in three steps. First, we should set the position signal's number according to the practical parameter of motor. Then, we should make out the phase shift logical table. In the end, let the output number matches the actual control.

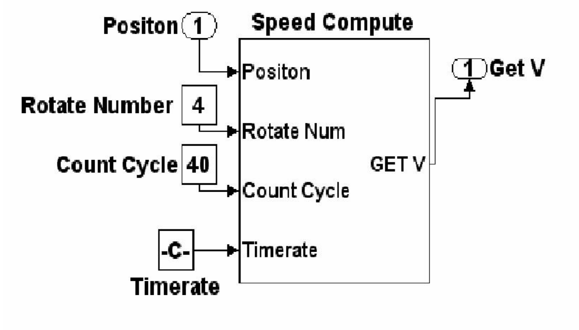

Fig. 4(a) Velocity collecting module (GET V)

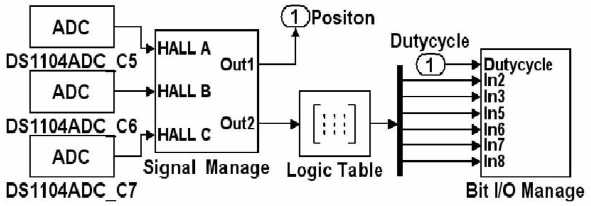

Fig. 4 (b) Phase conversion module (Commutate)

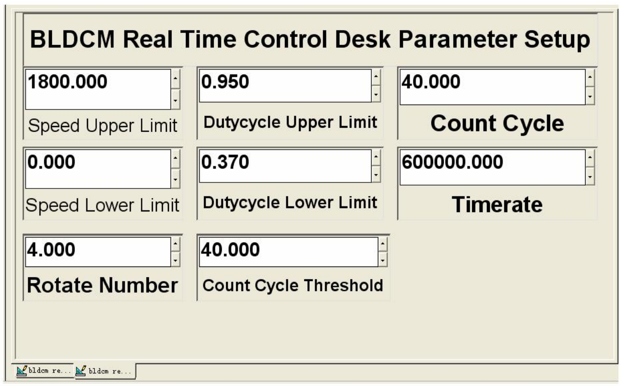

Fig. 5 Controls parameter set.

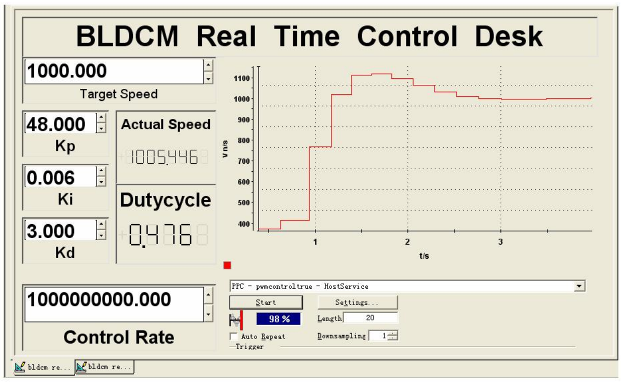

Fig.6 PID control example

For the safety of the whole system, we add a Security module (Security Limitation).The setup parameters are shown in Fig.5. The target speed's upper limit and lower limit could be fixed to prevent the motor rotating unnaturally. In addition, we could also set the duty cycle range of PWM to avoid appearance of rotor lock and oversized current. Some other parameters are set while it is working, by ControlDesk. Such as Fig.6, it is a PID control example. The PID control is a basal control algorithm, which can be used in many fields of electric machine control. We can set Kp, Ki, and Kd, the target speed at the moment when it is working, and obtain the velocity response curve in the picture. Absolutely, the response speed is good enough, while the overshot is obvious.

IV. Steps of Rapid Development Method

We can conclude the steps of rapid development of BLDCM's controller based on the common actuated circuit and controller model architecture.

As shown in Fig.7, first of all, we should judge whether the motor's parameters are equal to the actuated circuit. If it cannot satisfy the common actuated circuit's electric parameter, it has to redevelop a new one .With respect to very few algorithm that is unsuitable to be applied in the software model architecture, we could establish another model to continue the development.

In the consideration of cost reduction for corporations, we always attempt the control model without current loop, after we have finished the development with current loop. Finally, we get the hardware structure according as the devices practically operating; at the same time, Simulink generates the C code to be the control software. When it is a product development, we have nothing remains but to select apposite devices, design the hardware according to the obtained structure, make some necessary changes of the C code, and optimize them at last.

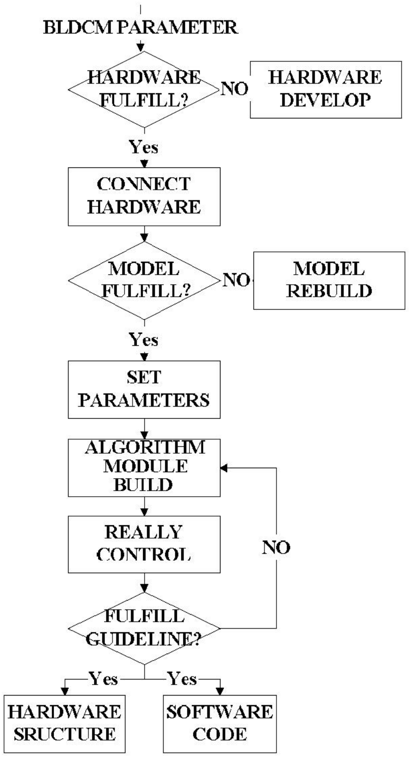

Fig. 7 Development Steps

V. Example

A corporation commissioned us to develop a kind of controller. It would be used to control the BLDCM applied on treadmills. In order to go with the new product's marketing, we had to accomplish it in two months. At last, according to the method mentioned in this article, we achieved the controller's development in time, and attained the corporation's requirement.

The target electric machine is a trio phase BLDCM with five antipodes, the parameters are shown in Tab.1.The treadmill's speed regulation range is 0.8km/h to 18km/h, and the maximum load is 180kg. The motor control's performance objective is shown in Tab.2. The basic objective is to control the BLDCM's speed from 150rpm to 4000rpm steadily, and ensure the force moment is between 2.15N•M to 5.25N•M while it is working. So the treadmill would reach the speed regulation range and its maximum load. Otherwise, the acceleration time and deceleration time is the standard to judging the startup and brake performance.

TABLE I

Parameter of Electric Machine

Parameter	normal rated power	normal current	normal speed
Value	2200W	12A	4000rpm
Parameter	maximum torque	electric resistance	
Value	5.25N•M	0.14Ω	
Parameter	rotation inertia	electrical inductance	
Value	13.2×10-4kg•m2	0.2mH	

TABLE II

TARGET OF CONTROL PERFORMANCE

Parameter	supply voltage	supply frequency	output power
Value	220VAC	50/60Hz	2200W
Parameter	force moment	rpm range	control precision
Value	2.15N•M /5.25N•M	150～4000 rpm	<±1%
Parameter	acceleration time(0~4000rpm)		
Value	<2s		
Parameter	deceleration time (4000~0rpm)		
Value	<2s		

According to design procedure, we were sure that the common actuated circuit satisfied the motor control's demand, and then we connected the hardware circuit directly. At the same time, referring to the common actuated circuit's hardware design, we devised the product's circuit. In power supply changeover part, we chose 220VAC; in each several part, devices were selected to match the electromechanical property. The sections that were not applied in the common actuated circuit would not be planned in the product's circuit any longer.

After analyzing the parameter of motor and the guideline of control performance, we adopted fuzzy control algorithm to realize start-up with slow speed and high pulling torque, and favorable ability of resistance to load impact. [9][10]We established the fuzzy controller by using Fuzzy toolbox in MATLAB. We figured out the deviation of the set speed and reaction velocity. Then, we founded the fuzzy logic relation of the deviation, the variation of the deviation, and the controlled variable. At last, we joined the fuzzy controller into the PACM's model architecture, and completed the settings for parameters of the architecture. [11][12]

According to the development steps, based on the common actuated circuit, we actually controlled the motor, and tested its control performance. After updating and optimizing, we obtained the velocity response curve shown as Fig.8. The whole acceleration time is no more than 1 second. In other words, the treadmill could achieve the target speed very quickly. And, when there is some load impact, which is the simulation of running estate, the velocity fluctuation is inconspicuous. So that, the man who is using the treadmill, will not feel the fluctuation of the speed. It also means that the running upon the treadmill will be the same as the running in the street.

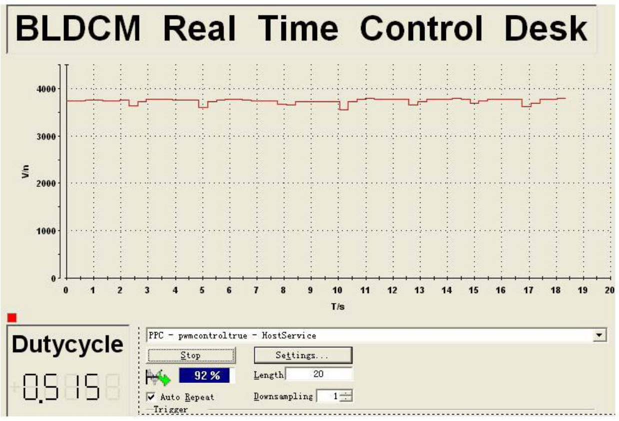

Fig. 8 (a) the curve of resistance to load impact

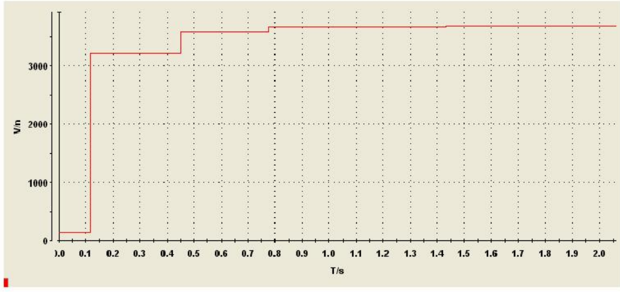

Fig. 8 (b) the curve of start-up with slow speed

In consideration of the cost and the controller demand, we chose PIC18F4431 to be the MCU. In order to match PIC's compiler MPLAB, we modified the C code automatically generated by MATLAB/Simulink.

We experimented on the treadmill using the developed product's circuit and software. The result indicates that the whole controller has achieved very good response speed and control precision. It fulfilled the guideline of the control performance .Its approved dynamic properties and resistance to load impact ability completely satisfies the failure-free operation of the treadmill.

VI. CONCLUSION

In order to develop BLDCM controller effectively, a method was propose in this paper. It was founded upon PACM and could be concluded into several steps. The PACM's hardware, a common actuated circuit based on dSPACE platform, could support the BLDCM below 3000W power. The PACM's software model architecture was made by combining dSPACE half-entitative simulation system and the modeling tool MATLAB/Simulink. And the controlling codes would be generated in dSPACE real-time simulative environment automatically. The whole model architecture contained six parts, such as position feedback, current feedback, actual speed calculation, phase shift logic, target speed set and control algorithm module. At last, in the guide of the steps we succeeded in developing a certain controller of a treadmill's BLDCM quickly. It indicated that this method was able to carry out on-line testing and analyzing of various control algorithms conveniently. It could increase the efficiency of BLDCM controller's development greatly.

REFERENCES

[1] Miller T J E. Brushless Permanent-Magnet and Reluctance Motor Drives [M].Oxford New York: Clarendon Press, 1989

[2] Awadallah M A, Morcos M M Switch fault diagnosis of PM brushless DC motor drive using adaptive fuzzy techniques[J].IEEE Trans. on Energy Conversion, 2004,19(1):220-237

[3] Lin ChingMin, Wai Rongjong, Hsu ChunFei. Fully tune adaptive fuzzy control for motor-toggle servomechanism[C].Advanced Intelligent Mechatronics, Kobe, J apan, 2003

[4] dsPACE. R&D Control Board Installation and Configuration [Z]. Paderborn: dsPACE GmbH, 2001

[5] dsPACE. Real-time interface implementation guide [Z]. Paderborn: dsPACE GmbH,2001

[6] dsPACE. Control desk experiment guide[Z].Paderborn: dsPACE GmbH,2001

[7] Xia Changliang, Wen De, Wang Juan et al. A new approach of minimizing commutation torque ripple for brushless DC motor based on adaptive ANN[J]. Proceedings of the CSEE,2002,22(1):54-58

[8] Jin Yaochu, Jiang Jingping. Two approaches to optimal fuzzy control[J]. Proceedings of the CSEE, 1996, 16(3): 201-204

[9] Qiu Albert, Wu Bin. Sensorless control of permanent magnet synchronousmotor using extended Kalman filter[C]. CCECE, 2004: 1557-1562.

[10] Becerra R C , Jahns T M ,and Ehsani M. Four Quadrant Sensorless Brushless ECM Drive [A] . IEEE Applied Power Electronics Conf. and Exposition[C], 1999: 202-209

[11] Song Hailong, Yu Yong, Yang Ming et al. A hybrid adaptive fuzzy variable structure speed controller for brushless DC motor[C]. IECON 02: Industrial Electronics Society, Sevilla, Spain, 2002

[12] Xia Yang, Zhang Tianping, Tang Hongru. Induction motor drives with direct torque control based on adaptive fuzzy control[C]. Intelligent Control and Automation, Shanghai, Chain, 2002