Design of DC Motor Speed Regulation System Based on ARM

He Chun-hong¹, Ren Bin²*
¹Research and Development Department, Guangdong somens Technology Group Co., Ltd, Dongguan, China
²School of Electronic Engineering and Intelligent, Dongguan University of Technology Dongguan, China
*Corresponding author, Email: renbin@dgut.edu.cn

Abstract: This paper mainly studies the design of DC motor speed control system based on ARM. The STM32 micro controller is used to design the corresponding hardware peripheral circuit, and the microcontroller programming, with the hardware circuit to achieve the corresponding function. Using the speed closed-loop PID control algorithm, the speed of the DC motor can be adjusted to improve the dynamic characteristics of the motor. The actual operation results show that the design of this topic is to meet the requirements of the control of the motor, such as start and stop, forward and reverse, acceleration and deceleration, and no steady state error.

1. Introduction
In recent years, the adjustment of the speed of the DC motor is more and more towards intelligent, fully digital, highly integrated direction. Compared with the control system composed of analog discrete components, there are many advantages of the DC motor speed control system using micro controllers. For example, the control method of the micro controller is more flexible, and the way of software control can be used to quickly change the control mode. Moreover, Micro controller internal processing signal is a digital signal, so its anti-interference ability, the control accuracy, speed, reliability and stability than the analog speed control system is much better.

In order to meet the requirements of the system for the rapid response and speed accuracy of DC motor, this paper mainly studies the micro processor with PID control algorithm to control the motor speed.

2. Brushed DC motor working principle and control methods
2.1 Brushed DC motor working principle and speed control method
As shown in FIG. 1 (a), the current of the DC power source flows in from the brush A. Since the brush A and the commutation plate 1 are in contact with each other, the current flows from the commutation plate 2 through the coil abcd of the commutation plate 1, 2 contact, the last current from the brush B outflow. We can see from the law of electromagnetic induction that the conductor ab and the conductor cd on one side of the coil will be affected by the electromagnetic force and the direction of the electromagnetic force can be judged by the left hand rule. The force on both ends of the conductor forms a counterclockwise torque, causing the motor's rotor to rotate counterclockwise.

Although the power supply is a direct current power supply, the current flowing in the motor coil is alternating due to the interaction between the brush and the commutation. The direction of the torque generated by the energized coil in the magnetic field is invariable, Rotate the motor in the given direction of rotation.

The voltage balance equation by the motor:  
\[ U_a = E_a + I_aR_a \]  
(1)

Back EMF in armature windings:  
\[ E_a = C_e \Phi n \]  
(2)

Know the motor speed calculation formula:  
\[ n = \frac{U_a - L_R a}{C_e \Phi} \]  
(3)

2.2 PID controller design

2.2.1 PID control principle

In this paper, the PID controller is programmed by software to realize its control algorithm, so the traditional analog controller must be discretized. Therefore, we need to use discrete difference equations instead of continuous differential equations. Assuming a short sampling time, you can use first-order differences instead of first-order differentials and accumulate instead of integrals.

The main role of PID parameters are as follows:

(1) Kp: The role of the ratio parameter is to speed up the system response speed and improve the system regulation accuracy.

(2) Ki: The integral parameter Ki's role is to eliminate the system's steady-state error. The larger the value of Ki, the faster the system's static error will be removed. Ki values need to be based on the actual system debugging, until it reaches a satisfactory control effect.

(3) Kd: The function of the differential parameter is to improve the dynamic performance of the system. If the Kd value is too large, the response process will be braked in advance, which will prolong the adjustment time of the system and reduce the anti-interference performance of the system.

In short, the adjustment of PID parameters, we should pay attention to the role of each parameter in the system response process and the inherent relationship between them, in practical applications based on the actual system for continuous debugging and verification, and ultimately can be satisfied with the control effect.
2.2.2 anti-integral saturation PID controller design

Due to the integral function of the PID controller, when the system has a deviation in one direction, the PID controller output will continue to increase, causing the motor speed to reach the limit value. If the output of the controller continues to increase, and the motor speed has reached the limit, does not increase with the controller output increases, then the controller output into the saturation zone. Afterwards, if the system shows the deviation in the opposite direction, the output of the controller will gradually exit the saturation area. The deeper the output of the controller enters the saturation area, the longer it takes to exit the saturation area. The actuator (motor) output does not produce the corresponding change immediately with the reverse deviation, so that the system control performance deterioration, which is the phenomenon of integral saturation. This design uses anti-integral PID control algorithm.

3. Hardware circuit design

3.1 Hardware Circuit Design overall block diagram

The system overall hardware circuit design shown in Figure 2, mainly by the power circuit, liquid crystal circuits, motor drive circuit, download debug circuit, encoder speed circuit built.

![System hardware design diagram](image)

3.2 system module circuit design

3.2.1 master chip selection

The main chip used in this project is STM32F103RCT6. The functions of this chip include: 2 basic timers, 256KB FLASH, 4 general purpose timers, 2 DMA controllers, 2 advanced timers, 3 SPIs, 5 serial ports, one 12-bit DAC, three 12-bit ADCs, 51 general purpose IO ports, and an SDIO interface.

3.2.2 Crystal and Reset Circuit Design

![Crystal oscillator circuit](image)  ![Reset Circuit](image)

This design of the system crystal oscillator circuit shown in Figure 3, the main frequency crystal oscillator with 8M quartz, with C1, C2 and a parallel 1M resistor for the system to provide a stable clock source. Clock using 32.678KHZ crystal oscillator, mainly for timing, the system standby or low power consumption.
Figure 4 is the system reset circuit, the system just power-up, the power VCC3.3 through the resistor R2 to the capacitor C4 charge, the voltage at the RESET point gradually increased until the voltage reaches the chip high low, the system reset, The system began to implement the program, after which the voltage at the RESET point continued to rise until about 3.3V. When the reset button is pressed RESET, the potential of the RESET point goes low, the capacitor C4 also releases the stored charge, then release the reset button, the C4 is recharged, the RESET point gradually increases to 3.3V, and the system finishes manually Reset.

3.2.3 system power supply circuit design

![Power circular socket]

In the circuit of Fig. 5, the 12V power supply comes from the power adapter. In addition to the power supply to the motor drive circuit, the 12V power supply utilizes the LM7805 voltage regulator chip to reduce the 12V voltage to 5V to supply other circuit modules in the system. Aluminum electrolytic capacitors C14, C15, ceramic capacitors C16, C17 main role to reduce the power supply ripple and filter out the power clutter for the system to provide a more high-quality power supply.

In the circuit of Fig. 6, 5V power mainly comes from the USB interface power supply and the power that is converted to 5V after 12V. After the system switch, the 5V power supply is stepped down to 3.3V power supply by using the AMS1117-3.3 voltage regulator chip and the system Other circuit modules to use. Aluminum electrolytic capacitors C19, C21, ceramic capacitors C20, C22 role and the aforementioned aluminum electrolytic capacitors and ceramic capacitors consistent role, are designed to provide higher quality system power supply.

![Fig.5 12V to 5V circuit]

3.2.4 Encoder circuit design

Figure 7 is the circuit board encoder interface circuit, through the pin will STM32F103RCT6 encoder interface corresponding IO port leads. Assuming that the two input signal channels of the encoder are TI1 and TI2, respectively, the counter has been started and the counter is driven by a valid transition on each TI1 or TI2, the count pulse and direction are generated according to the transition order of the two input signals signal. According to the order of the two input signals, the counter counts up or down. At the same time, the hardware sets the DIR bit in the TIM_CR1 register. The DIR bit will be recalculated when the input signal path of the encoder changes.

In order to improve the accuracy of the encoder, you can use encoder software 4 times frequency technology, the encoder accuracy of 4 times. Figure 8 is a simple schematic of the software 4x frequency technique.

![Fig.6 5V to3.3V circuit]

In normal circumstances we use M method speed, only by measuring the number of output pulses per unit time A phase to get speed information. According to the conventional method, only the rising edge or the falling edge of the A phase (or B phase) is measured, corresponding to any one of the numbers 1234 in FIG. 10, so that in the measurement cycle shown in FIG. 8., And the software 4x frequency method is to measure the A and B phase encoder rising and falling edge, so that in the
measurement period shown in Figure 10, you can count 12 times, this is the software 4 times the frequency Fundamental.

3.2.5 motor drive circuit design

The driver circuit mainly consists of a 74HC244 chip and two BTN7970 chip set up, two BTN7970 driver chip respectively control the motor forward and reverse. The R9, R10, R11 and R12 in the design circuit are pull-down resistors, ensuring the input 74HC 244 level is stable. When there is an indefinite level, the level is pulled low.

4. software programming

4.1 system initialization

The design of the software part of the block diagram shown in Figure 10. System power, the program began to initialize the various modules in the system. For the design, the modules to be initialized are: the system clock, USART baud rate, LED lights, PID controller, TFT-LCD liquid crystal display, external interrupt, PWM output, timer and encoder interface, In this process, the initial setting of each module parameter is realized and the task of system allocation is completed.

4.2 speed setting

Gear is divided into ten files, each file speed increase 1 r / min, the minimum is 0 r / min, the maximum is 10 r / min. When the acceleration (deceleration) button is pressed, the speed setpoint will add (subtract) the current gear value on the current basis. The main function of the gear setting is to facilitate rapid addition and subtraction of the speed. If there is no gear setting function, the acceleration and deceleration will need to press the acceleration / deceleration key several times. If the value of increase (decrease) of each key press is set as Setting, it is impossible to achieve any speed adjustment within the motor speed range.

4.3 encoder speed

Encoder speed by the master chip encoder interface circuit to complete, STM32 comes with encoder
interface circuit, after a certain configuration, the use of this feature can be very easily measured motor speed.

The method used to calculate the speed of the design for the M method speed. In this design, the motor rotates one circle, the Hall encoder output pulse is 390, after the software multiplier 4, the actual number of pulses measured 1560, the system sampling period of 100ms, set before and after the two measurements The difference between the values of TIM->CNT is ΔCNT, then the calculation formula of the speed of M method is:

\[
\text{Speed} = \frac{60 \times \Delta\text{CNT}}{1560 \times 0.1} \text{ r/min}
\]  

(4)

This value is compared with the set speed value to get the speed deviation, the deviation sent to the PID controller for the appropriate treatment.

### 4.4 PID control algorithm design

The design of the PID control using position control algorithm, the sampling period of 100ms. PID position control algorithm formula is:

\[
U_k = K_p \times e_k + K_i \times \sum e_k + K_d \times (e_k - e_{k-1})
\]  

(5)

After the deviation is processed by the controller, the obtained value is assigned to different PWM channels according to the control requirements of forward and reverse rotation. In the present design, the two PWM channels are the channel 1 and the channel of the timer 1 respectively 4, i.e., TIM1->CCR1 and TIM1->CCR4, the duty cycle of the corresponding channel output PWM can be changed by changing the value of TIM1->CCR1 or TIM1->CCR4 to achieve the purpose of controlling the motor rotation and speed.

![Fig.10 Software design flow chart](image)

#### 5. System parameter debugging and result analysis

The design of the motor used for the brush DC gear motor, the reduction ratio of 30, rated voltage of 12V, rated current of 360mA, power of 4.32W, no-load speed of 366RPM, the original speed of 11000RPM, rated torque of 1kgf.cm.
5.1 PID parameter adjustment steps
PID parameters to adjust the basic steps:

(1) Determine the proportional parameter $K_p$: Let $T_i$ and $T_d$ be equal to 0, then PID is pure proportional adjustment. Gradually increase the $K_p$ from 0 until the system oscillates, and then gradually reduce the value of $K_p$ from $K_p$ at this time until the system oscillation disappears. Record the $K_p$ and complete the adjustment of the proportional coefficient.

(2) Determine the integral time constant $T_i$: Set a larger initial value of the integral time constant $T_i$ after determining the proportional coefficient, and then gradually reduce the value of $T_i$ until the system oscillates, and gradually increase from this value Large $T_i$ value until the system oscillation disappears. Complete the integral time constant $T_i$ debugging.

(3) determine the differential time constant $T_d$: differential time constant is generally 0. If you want to set, then with the above-mentioned method of determining the proportional parameters and integral time constant, take 30% of the value when no oscillation.

5.2 Determination of PID parameter

5.2.1 Determination of the proportional parameter $K_p$:

![Fig.11 Kp=300, Ki=0, Kd=0](image1)

![Fig.12 Kp=400, Ki=0, Kd=0](image2)

From Fig.11 to Fig.13, it can be seen that the system oscillates when $K_p = 450$; when $K_p = 400$, the system converges, but it takes a long time to make the system stable around the set value; when $K_p = 300$, The system converges, and make the system stable in the setting value of the shorter time required, $K_p$ value can speed up adjustment speed, $K_p = 300$ also can meet the adjustment time requirements, so take $K_p = 300$, $K_p$ debugging completed.

![Fig.13 Kp=450, Ki=0, Kd=0](image3)

5.2.2 Determination of the integral parameter $K_i$
As can be seen from Figures 14 to 16, when the integral coefficient is large, the overshoot of the system response curve is also large, and the time required for the response curve to reach the steady-state value is also relatively long. Finally, these three values of $K_i$ can eventually So that the system reaches the control requirements without steady-state error, taking into account the overshoot and adjustment time, take the value of $K_i$ is 1.

![Fig.14 Kp=300, Ki=20, Kd=0](image4)

![Fig.15 Kp=300, Ki=10, Kd=0](image5)
5.2.3 Determination of the differential parameter $K_d$

As can be seen from Figs. 17 to 19, when the value of $K_d$ is small, the differential action is weak, and the difference of the differential component cannot be seen and the value of $K_d$ is gradually increased. When $K_d = 1.5$, the differential component The role of the system to adjust the time smaller. Continue to increase the value of $K_d$ to 10 and 30, we can see that the system adjustment time becomes larger, the system dynamic performance deterioration.

6. Conclusion

By observing the actual operation of the system, the design can be achieved on the motor forward, reverse, start, stop, no steady-state error control requirements. At the same time through the LCD screen to understand the motor speed setpoint, the actual value, the motor rotation status and speed curve and other information, you can very intuitively understand the real-time motor running information.

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