Servo Control of Brush DC Motor with Variable Load

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Abstract. In this article, in view of the characteristics of the cash circulation module of financial machines, such as fast note entering and going out of the note box and large change of load, a control system of fuzzy speed regulation of the note box based on the existing brush driven DC motor through simple feedback signals is designed, so as to realize the stable note output of the note box under varying load. Through experimental verification, after the speed adjustment of the note box, the change in the delivery speed of note has been greatly reduced, and the time change rate of each note transmission has been controlled below 4%, which meets the design expectations and meets the requirements of the system, and can be used as a reference for design in related fields.

1. Introduction

The stacked banknotes in the circulating banknotes box of cash circulation module are sent one by one to the transmission channel by motor. The load of the motor changes in real time with the money transfer. In order to ensure the reliability of system transmission, the speed of the motor should be stable under the circumstance of changing load. At the same time, the banknote box space is small, requiring light weight, so precise drive stepper motor and other large motor cannot be used. How to make full use of the brush-dc motor small volume, rapid response, large starting torque characteristics and design a control system to make the motor stable operation under variable load through speeding regulation become the goal of this design.

Speed control of brushless dc motor generally includes three methods: fixed-width frequency modulation method, frequency modulation width modulation method and fixed-frequency width modulation method [8]. According to the requirements of the system, the design adopts the method of frequency modulation and width adjustment to control the speed of the brushless dc motor, so as to realize the system's requirement of stable speed of paper money.

2. System control principle

The relationship between the speed of dc motor and other parameters can be shown as [1] :

$$n = \frac{U_a - I_a R_a}{C_E \emptyset} \tag{1}$$

$U_a$is the voltage of the motor, I_a is armature current,$\emptyset$ is excitation flux, $R_a$is the armature loop total resistance, C_E is potential coefficient, $C_E = \frac{pN}{60a}$, p is the electromagnetic logarithm, a is the number of armature parallel paths, N is the number of conductors.

The rate control system only has the motor control system with rate negative feedback [1]. The system uses the special brush DC motor driver STA6940M itself with over current protection, so the system

only uses the speed controller, by adjusting the frequency and duty ratio of the voltage at both ends of the DC motor, to achieve the control of the motor running speed. The control principle of this system is shown in figure 1. The system detects the speed of the motor through the speed feedback signal of the dc motor, so as to adjust the speed of the motor.

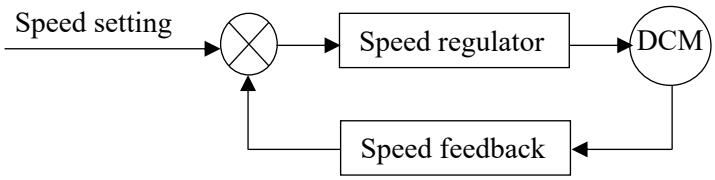

Figure 1. Control schematic diagram of the system

3. The composition of the control system

The control of brush DC motor is generally divided into controlling the voltage at both ends and armature current.The brush DC motor control system is shown in figure 2.

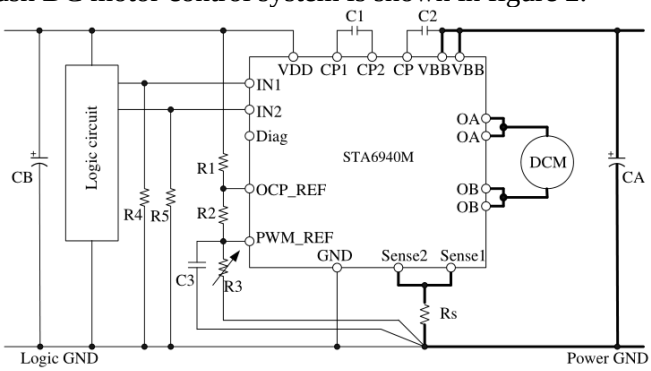

Figure 2. STA6940M application circuit

The system uses Brush DC motor driver IC (STA6940M) of SanKen company to drive the brush DC motor. STA6940M has built-in overcurrent and overheat protection circuit to simplify the system hardware protection circuit and improve the reliability of the system.

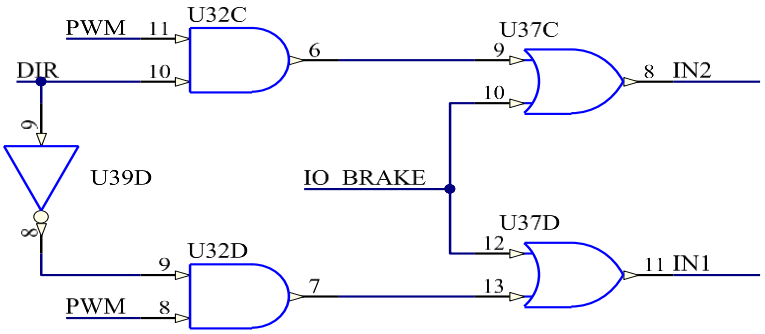

Figure 3. STA6940M control logic circuit diagram

STM32F437IIT6, the ARM core microcontroller of the system, outputs three control signals: speed control signal PWM of brush DC motor, BRAKE of brush DC motor, and running direction signal DIR of brush DC motor. The relationship between the three signals and the state of brush-dc motor is shown in table 1.

Table 1. STA6940M logic circuit table

PWM	BRAKE	DIR	STA6940				DCM state
			IN1	IN2	OA	OB	
0	0	X	L	L	Z	Z	Free
PWM	0	L	H	L	H	L	Forward

PWM	0	H	L	H	L	H	Reverse
X	1	X	H	H	L	L	Brake

The system uses photoelectric switch to detect the speed of the brush DC motor, and adjusts the output level of PWM, the speed control signal of the brush DC motor, through the periodic value of the output signal S of the photoelectric switch, so as to realize the adjustment of the running speed.

The velocity feedback signal T_S is input to STM32F437IIT6 through the shaping circuit of RC filter and comparator. The photoelectric switch signal filtering shaping circuit is shown in figure 4.

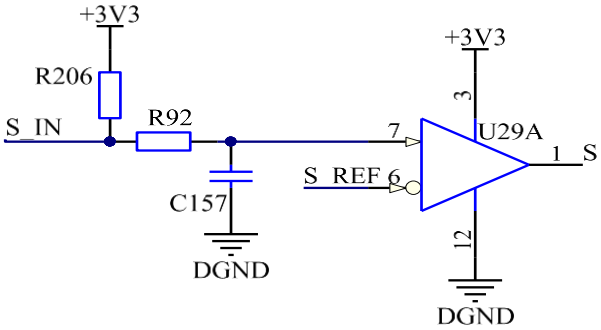

Figure 4. Speed feedback signal S processing circuit diagram

4. Algorithm design

4.1. Theoretical value of motor speed feedback signal

The parameters of the brushless dc motor used in the system are: rated voltage 24V, system no-load speed is 5360r/min. The system requires the running speed of paper money to be divided into 10 pieces/second. According to the friction wheel of the dc motor mechanism, the deceleration ratio of the grating ruler and the number of holes in the grating, the running speed of paper money, the running period of paper money, the s-period value of the grating signal feedback from the motor and the motor speed are shown in table 2.

Table 2. T_S table of theoretical calculation value of speed feedback signal

Speed of note (Piece/s)	Note cycle (ms)	T_S theoretical value (us)	Motor speed (r/min)
10	100	850	4050

4.2. PWM output of motor speed control signal

The system input the speed feedback signal T_S through the RC filter and comparator shaping circuit to the timer counting pin of STM32F437IIT6 microcontroller. When the first T_S signal rises, the timer starts to count. Present a rising edge of the T_S signal, trigger a microcontroller timer interrupt again, read the timer count, measurement to the cycle of T_S values compared with the parameters of table 3, if T_S measurements > T_S actual values, the microcontroller PWM output port high level, the motor speed operation; If T_S measurement value <T_S actual value, then the microcontroller PWM port output low level, motor deceleration run. Then clear the timer count register 0 to start the next count， and repeat this process, for each of the T_S signal cycle measurement, Adjust motor speed.

5. The experimental data

The experimental results of the system are shown in the following figures, which include the note running speed signal (channel 1), motor speed feedback signal T_S (channel 2), and operation control signal PWM (channel 3) of the brush DC motor.

The paper note with a width of 77mm was used for measurement in the experiment. The specific waveform is shown in Figure 5 and Figure 6.

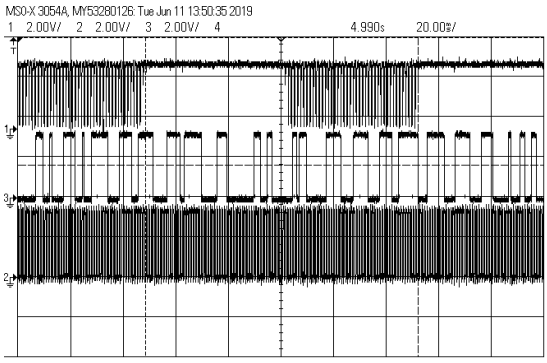

Figure 5. maximum period of 10 pps

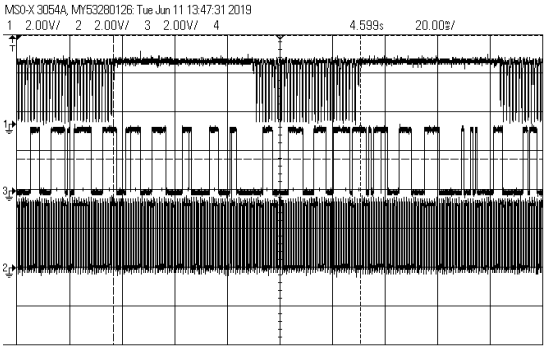

Figure 6. minimum period of 10 pps

The minimum value appears only on the first note shipped, and the rest of the notes have a period of approximately $_{MAX}$. Ignoring the running period of the first note, the error between the actual running speed and the theoretical speed is less than 4%, as shown in table 3. Meet system error requirement.

Table 3. Note cycle maximum and minimum value

Speed of note (ms)	Note actual minimum period T_{MIN} (ms)	Note actual minimum period T_{MAX} (ms)
100	94	104

6. Conclusion

In this system, the brush DC motor load changes in real time, using feedback real time (T_S) fuzzy speed regulation of brush DC motor, and finally achieves the requirements of steady speed operation of the motor.Moreover, the fuzzy speed regulation method is flexible, the motor adjustable speed range is large and high precision, the system debugging parameters are few, easy to meet the requirements of the system speed classification. When the delivery speed of notes is 10 pieces/s, the transfer time of each note is required to be 100ms. Taking the note width of 77mm as an example, the actual measured output value is 94ms~104ms, which basically conforms to the system requirements and meets the system requirements.

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