



Design of Step Motor Automation Control System Based on Lyapunov Stability Theory

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Abstract. In order to improve the effect of stepping motor automation, the design method of stepping motor automation control system based on Lyapunov stability theory is proposed. Firstly, AT89C52 MCU is used to optimize the hardware configuration of stepping motor automation control system, and the system operation algorithm and operation steps are perfected.

Keywords: Lyapunov stability theory · Stepping motor · Automation

1 Introduction

At present, SCM has become an important application field of modern electronic technology and computer technology. The stepper motor automatic control system represented by SCM has been regarded as the symbol of modern electronic system era. At the same time, because the price of single-chip microcomputer is relatively low, it makes the application of single-chip microcomputer in stepping motor automatic control system more widely, and also promotes the transformation of more classical stepping motor automatic control system to modern electronic system [1]. Stepper motor is an open-loop control element that converts electric pulse signal into angular displacement or linear displacement. In the case of non overload, the speed and stop position of motor only depend on the frequency and pulse number of pulse signal, and are not affected by load change. In addition, stepper motor has only periodic error but no cumulative error. In the field of position control, it is very simple to use stepper motor to control [2]. In order to realize the real-time, fast and accurate control of eight two-phase bipolar hybrid stepping motors, Lyapunov stability theory is used to study the automatic control system of stepping motor. Lyapunov stability theory was founded by Russian mathematician Lyapunov in the 1880s. It has been widely used in automatic control, aviation technology, ecological biology, biochemical reaction and other natural science and engineering technology, and its concept and concept have also developed very rapidly. Using the characteristics of pulse drive of stepper motor, to achieve its control. The system controls the lower computer through the upper computer man-machine interface. The lower

computer uses the combination of arm and FPGA to control multiple stepper motors. In order to realize multi-channel control of stepper motor, the upper computer can send control instructions through arms and FPGA, and FPGA can generate pulse control signals needed for motor start, acceleration, deceleration, stop, step adjustment, speed adjustment, etc. through control instructions [3]. The pulse signal needed to control each motor is input into the corresponding motor controller through FPGA. Practice has proved that Lyapunov stability theory is very suitable for the control of stepping motor, and its many characteristics, such as short development cycle, high flexibility, low cost and high integration, make it the preferred object in the field of stepping motor control [4]. Taking Lyapunov stability theory as the core of microcontroller not only reduces the cost of the whole control system, simplifies the hardware circuit, but also fully ensures the strong stability and feasibility of the system.

2 Design of Automatic Control System for Stepping Motor

2.1 Optimization of Hardware Configuration Structure of Stepping Motor Automatic Control System

Stepper motor control system and other motor control system can use open-loop control, must include a special driver to drive stepper motor. Stepper motor control system is mainly composed of three parts: stepper motor body, stepper motor drive circuit, stepper motor controller [5]. The system consists of upper computer, STM32 microcontroller and cyclone II FPGA. Through the host computer to complete human-computer interaction, using STM32 and FPGA as the core processor of the control system, can effectively and reasonably allocate resources. The relevant operation parameters that need to be set for the operation of the stepper motor can be modified through the operation interface of the upper computer. STM32 sends the operation commands and parameters to FPGA, and generates the digital pulse control signals needed for the start, acceleration, deceleration and stop of the stepper motor through the control commands [6]. The control system is developed on the basis of the existing STM32 development board and cyclone II FPGA development board. The main work is to complete the development and test of the system on the basis of the existing hardware circuit. Based on this, the system framework is optimized, as shown in the Fig. 1.

From the above picture, we can know that the multi-channel stepper motor control system includes the human-computer interface, ARM microcontroller, FPGA pulse controller, stepper motor driver, stepper motor body and so on. The human-computer interaction control interface of the upper computer is the window for the whole control system to communicate with the outside world [7]. It not only makes the whole control system visualized, but also makes the running state of each channel stepping motor get real-time monitoring. Through this interface, the system operators can set up the parameters of the entire control system, command settings, stepping motor channel number selection and other operations [8]. In addition, the PC will also send ARM synchronous motor running state conversion related control instructions, such as start, acceleration, deceleration and so on. In the STM32 control module circuit, hardware resources, we

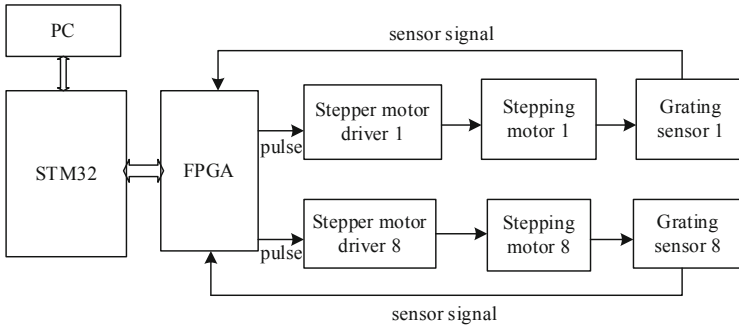


Fig. 1. System hardware configuration structure diagram

must provide several hardware circuits, including: power module, JTAG debugging module, crystal module, serial port module and GPIO universal IO port module. Figure 2 shows the block diagram of STM32 microcontroller.

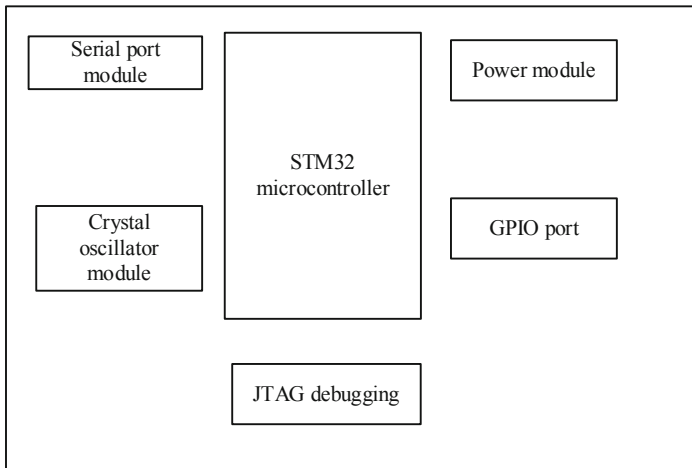


Fig. 2. STM32 microcontroller block diagram

As shown in the picture above, this control system mainly includes six parts: PC, STM32, FPGA, stepper motor driver, stepper motor and grating sensor. In order to allocate resources reasonably, the control system adopts modular design, which can communicate with each other and transfer information effectively, so as to control the stepper motor accurately. Based on this, the system hardware structure and functions are further optimized as shown in Fig. 3:

In order to realize the visualization of the control system, the operation interface of the upper computer is designed by Delphi 7, and the communication with the lower computer is completed by serial port (RS232) [9, 10]. The STM32 series 32-bit flash memory microcontroller is very suitable for control applications because of its low

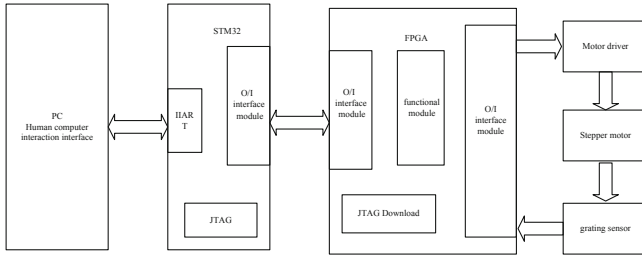


Fig. 3. System hardware structure function optimization

power requirements and low cost. STM32 can receive the control command and related operation parameters sent by the host computer, and then control the operation of the stepper motor, through software programming, the parameters are sent to the FPGA. In addition, in the design of this module, timer interrupt is needed to read the current state of each channel stepping motor from FPGA, and feedback the data to PC through serial communication.

2.2 Step Motor Automation Control System Software Operation Algorithm

In the mechanical transmission process in order to make a smaller pulse equivalent, one can change the lead screw, and the other can be achieved through the stepping motor subdivision drive. But subdivision can only change its resolution, not its accuracy. The accuracy is determined by the inherent characteristics of the motor [11]. The load inertia of stepper motor and the starting frequency required by the machine tool should be estimated to match the inertia frequency of the stepper motor, so that the high-speed continuous working frequency can meet the need of the machine tool moving rapidly. The following calculations are required for selecting a stepper motor:

Based on the required pulse equivalent, the gear reduction ratio *i* is calculated as follows:

$$i = \frac{\varphi}{360\Delta} S \tag{1}$$

φ is the step angle of the stepping motor, *S* is the screw pitch, where the screw and gear are converted to the inertia of the motor shaft:

$$J_t = J_1 + \frac{i}{i_2} \left[J_2 + J_s + \frac{W}{g} \left(\frac{S}{2\pi} \right)^2 \right] \tag{2}$$

It is the inertia converted to the motor shaft, *J*₁, *J*₂ are the inertia of the gear, *J*_s is the inertia of the screw rod, and *w* is the weight of the worktable

$$M = M_a + M_f + M_t \tag{3}$$

The expression *M*_{*a*} of the parameter is:

$$M_a = \frac{(J_s + J_t)n}{MT} \times 1.02 \times 10^{-2} \tag{4}$$

M_a is the starting acceleration torque of the motor, M_f , M_t are the inertia of the motor itself and the load, n is the required speed of the motor, and T is the speed up time of the motor

$$M_f = \frac{uWS}{2M_a\pi\eta i} \times 10^{-2} \tag{5}$$

η is the torque converted from the rail friction to the motor, P_t is the friction coefficient, and i is the transmission efficiency. Then the starting frequency of system load is estimated

$$M_t = \frac{P_tS}{2M_f\pi\eta i} \times 10^{-2} \tag{6}$$

The starting frequency of the motor controlled by the numerical control system is closely related to the load torque and inertia

$$f_q = f_{q0} \left[\left(1 - \frac{M_f + M_t}{M} \right) \div \left(1 + \frac{J_t}{J_s} \right) \right]^{\frac{1}{2}} \tag{7}$$

According to the given value $rin(t)$ and the actual output value $yout(t)$, the control deviation is obtained

$$error(t) = f_q rin(t) - yout(t) \tag{8}$$

Then the automatic control law of self motor is as follows:

$$u(t) = k_p error(t) + \frac{1}{T_I} \int_0^t error(t)dt + \frac{T_D derror(t)}{dt} \tag{9}$$

Then the transfer function of motor automatic control is as follows

$$G(s) = \frac{U(s)}{E(s)} = k_p \left(1 + \frac{1}{T_I s} + T_D s \right) \tag{10}$$

Where K_p is the proportional coefficient, T_i is the integral time constant and T_N is the differential time constant.

Based on the above algorithm, according to the function and design requirements of each part of the system, the software part of the control system can be roughly divided into two parts: the success module and the communication module. According to the hardware part, the function module can be divided into upper computer part, STM32 module and FPGA module [12]. The communication module consists of two parts: the communication between upper computer and STM32, and the communication between STM32 and FPGA. Based on this, the operation information processing steps of stepping motor automatic control system are optimized, as shown in Fig. 4.

As shown in the Fig. 4, the initialization operation of the system main program mainly includes system clock initialization, flash initialization, interrupt initialization, peripheral initialization, control and function initial parameter reading, and then turn on the interrupt to enter the main cycle [13]. In the process of operation, the stepper motor

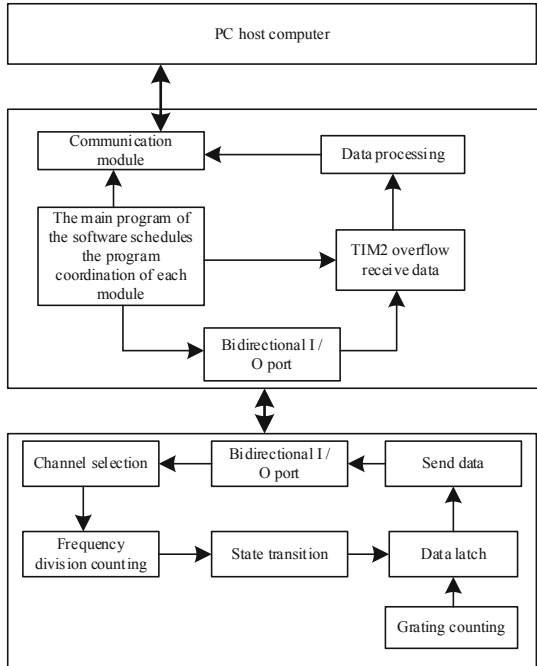


Fig. 4. Operation information processing steps of stepping motor automatic control system

cannot be directly driven by DC or AC power supply. Therefore, the classic combination of L97 + L298 is used in the driving circuit of the system. After loop distribution and power amplification, the pulse output from FPGA is input into the stepper motor, and finally drives the specified stepper motor. The hardware circuit of the driver is simple, the cost is low, and the effect of the driver is good. The specific main program flow is shown in Fig. 5.

As shown in the figure, when selecting the stepper motor, the output power of the stepper motor must be greater than the power required by the load. When selecting the power stepping motor, the load torque of the mechanical system should be calculated first. The torque frequency characteristics of the motor can meet the mechanical load and have a certain margin to ensure its reliable operation [14]. In the actual working process, the load torque under various frequencies must be within the range of torque frequency characteristic curve. In addition, the step angle should be matched with the mechanical system so that the pulse equivalent required by the machine tool can be obtained.

2.3 Realization of Step Motor Automatic Control

Stepper motor driver is a necessary part of motor control, including optical isolation module, power amplifier module and output module. The output module transmits the pulse signal after power amplification to the stepper motor to drive each motor. There are two main functions of the optical isolation function module: receiving the pulse signal sent by FPGA; isolating the optical coupler before receiving the pulse signal [15]. The

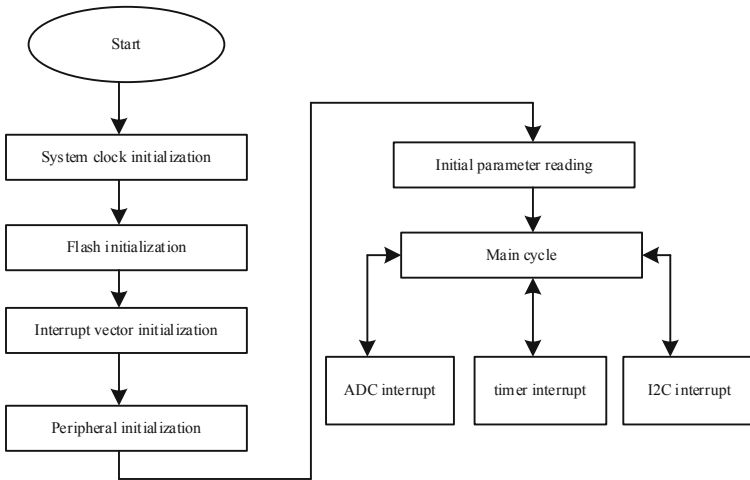


Fig. 5. Simplification of main program operation steps

most important part of the stepper motor driver is the power amplifier module, because the pulse sent by FPGA is not enough to drive the motor, and the function of the power amplifier module is to distribute the pulse signal and amplify the power. Stepper motor control system is an organic whole, which is composed of motion control system and operation control system [16]. The operation system converts the operator’s operation into the electrical signal that the motion control system can accept, and the motion control system responds and completes the specified action. Based on this, the operation control method of stepping motor automatic control system is optimized, as shown in Fig. 6.

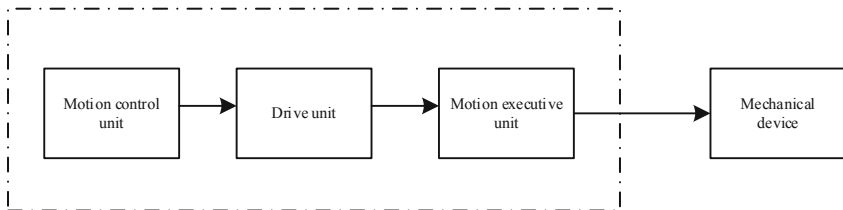


Fig. 6. Step motor automatic control method

The control system must apply a certain pulse signal to the stepper motor to drive it to run, but the pulse signal output by FPGA is small enough to drive the motor to run, so the driver needs to amplify the pulse signal output by FPGA. In the course of the development of stepper motor, a variety of special stepper motor drivers have been designed and developed [17]. Figure 7 shows the basic composition of the stepper motor driver, as follows:

In the stepper motor control system, the motion executive component is stepper motor. Stepping motor is a kind of actuator which converts electric pulse into angular displacement. When the stepper driver receives a pulse signal, it drives the stepper motor

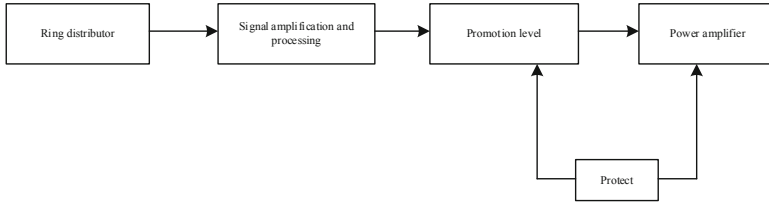


Fig. 7. Basic composition and structure optimization of stepper motor driver

to rotate a fixed angle according to the set direction, and its rotation is running step by step at a fixed angle. The angular displacement can be controlled by controlling the number of pulses, so as to achieve the purpose of accurate positioning. At the same time, the speed and acceleration of motor rotation can be controlled by controlling the pulse frequency, so as to achieve the purpose of speed regulation [18]. The operation of the stepper motor needs an electronic device to drive. This device is the stepper motor driver, which amplifies the pulse signal sent by the control system to drive the stepper motor. The speed of the stepper motor is proportional to the frequency of the pulse signal. Controlling the frequency of the step pulse signal can speed the motor accurately; controlling the number of step pulses can position the motor accurately [19]. Different results can be obtained by different data operations on LCD controller. For English display, only 8 bits (one byte) are needed. There are more than 6000 commonly used Chinese characters, so we use the 128 rarely used values in ASCB table as a group to represent Chinese characters, that is, the internal code of Chinese characters, and leave the lower 128 bits for English characters, that is, the internal code of English. Use the information of numbers to record the shape of English or Chinese characters. See Table 1 for system operation pin description.

Using single-chip microcomputer to drive stepping motor by software, not only can we freely set the speed, rotation angle and rotation times of stepping motor within a certain range through programming method, but also can conveniently and flexibly control the running state of stepping motor to meet the requirements of different users. The control system realizes the remote control of the upper computer, and the running state of the stepping motor can be displayed through the LCD screen [20]. Based on the pin description, the operation steps of the automatic control system are further optimized, as shown in Fig. 8.

In the whole process of system debugging, single step execution and full speed execution can be combined organically to find the wrong location more quickly and accurately than single method. Full speed execution can cooperate with setting breakpoints, which can generally determine the error range. Single step execution can understand the execution of each instruction in the program in detail, and it is convenient to know whether the instruction is correct by comparing the operation results of the instruction. On the basis of realizing the control of single stepping motor, the control system also needs to realize the synchronous control of multiple stepping motors. In the process of debugging, it is necessary to use oscilloscope to intuitively judge the synchronization of FPGA output control pulse. The specific method is to input the FPGA output pulse corresponding to any two synchronous control stepping motors into the oscilloscope when debugging

Table 1. System operation pin description

Pin number	Pin name	Level	Pin function description
1	VSS	0 V	Power ground
2	VCC	- 5 V	Power supply positive
3	V0	H/L	Contrast (brightness) adjustment
4	RS(CS)	H/L	Rs = "H" indicates that db7-db0 are display data Rs = "L" indicates that db7-db0 is the display instruction data
5	R/W(SID)	H/L	The data is read to db7-db0 The data of db7 → db0 are written to IR or Dr
6	E(SCLK)	H/L	Enable signal
7	DB 0	H/L	Tri state data line
8	DB 1	H/L	Tri state data line
9	DB 2	H/L	Tri state data line
10	DB 3	H/L	Tri state data line
11	DB 4	H/L	Tri state data line
12	DB 5	H/L	Tri state data line
13	DB 6	H/L	Tri state data line
14	DB 7	H/L	Tri state data line
15	PSB	H/L	H: 8-bit or 4-bit is parallel port mode, l: serial port mode
16	NC	-	Empty feet
17	/RESET	H/L	Reset terminal, low level valid
18	VOOUT	-	LCD driving voltage output terminal
19	A	VDD	Positive end of backlight (+ 5 V)
20	K	VSS	Negative end of backlight

the system, and observe and compare, so as to ensure whether the system reaches the synchronization index.

3 Analysis of Experimental Results

Matlab/Simulink is used in the simulation. MATLAB is a simple engineering calculation language launched by MathWorks company in the United States. Based on matrix, it integrates calculation, visualization and programming into an interactive working environment. It can realize the functions of engineering calculation, algorithm research, modeling and simulation, data analysis and visualization, scientific and engineering drawing, application development and so on. When all parts of the system are debugged successfully, the system runs normally, and the upper computer interface and FPGA

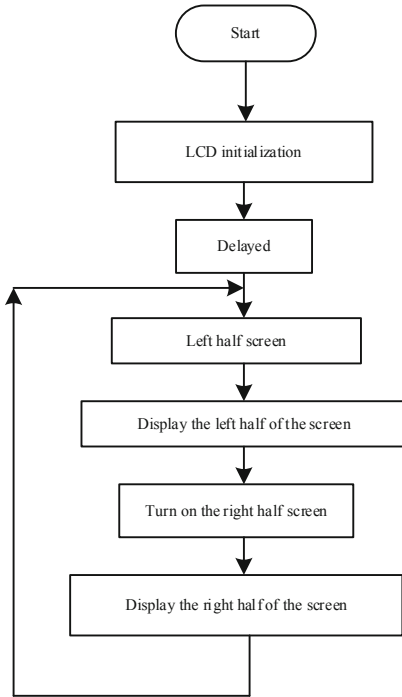


Fig. 8. System operation steps

Table 2. Experimental parameter setting

Setting parameters	Parameter value
Steps	500000 steps
Initial speed	50 steps per second
Target speed	5000 steps per second
Stop speed	50 steps per second
Acceleration	500
Deceleration	500

output pulse are observed. Here, the control system is set to 8-channel synchronous operation parameters as experimental parameters, as shown in Table 2.

Generally speaking, the automatic operation state of stepping motor is the same. In the process of experiment, we only need to measure and observe the pulse of any channel. When the stepper motor enters the stable operation state, the FPGA output pulse of the system is displayed, and according to the output result, the motor is adjusted to run in time. In order to form the experimental contrast, the traditional stepper motor control system and the DSP based stepper motor control system are set as the two contrast systems

of the experiment, and the system is developed and operated in the same environment to ensure the uniqueness of the experimental variables. After the system running, the display result of stepping motor output pulse is shown in Fig. 9.

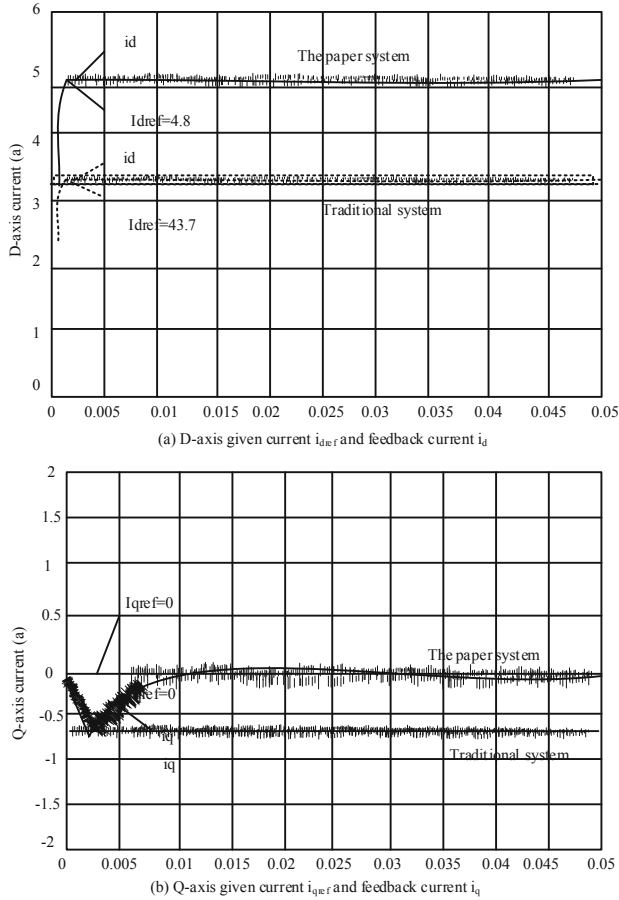


Fig. 9. Analysis of experimental comparison results

The simulation results show that compared with the traditional system, the control scheme based on Lyapunov stability theory is feasible. Based on the traditional system operation curve in the figure, it can be seen from the torque speed characteristic curve, current speed characteristic curve and current waveform of stepper motor system that with the increase of speed, the current amplitude and torque output capacity of the system decrease. This is because the back EMF increases with the increase of stepper motor speed. This is the inherent characteristic of stepping motor.

4 Conclusion

The design of stepping motor automatic control system based on Lyapunov stability theory is put forward. From the actual use, the controller has the characteristics of high reliability, easy to use and strong universality. The control of stepping motor runs smoothly and the effect is good. With the development of microelectronics and computer technology, the operation of stepping motor automatic control system based on Lyapunov stability theory will be more simple, flexible and intelligent, and will be widely used in various fields.

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References

1. Zhiyong, D., et al.: A Global Convergence Estimator of Grid Voltage Parameters for More Electric Aircraft. *IEEE Trans. Indus. Electron.* **67**(9), 7540–7549 (2019)
2. Wang, Y., et al.: Visual servo-collision avoidance hybrid task by considering detection and localization of contact for a soft manipulator. *IEEE/ASME Trans. Mechatron.* **99**, 1–1 (2020)
3. Qiu, B., et al.: Synchronization of multi-links memristor-based switching networks under uniform random attacks. *Neural Process. Lett.* **48**(3), 1431–1458 (2018)
4. Zhang, D., et al.: Stepper motor open-loop control system modeling and control strategy optimization. *Arch. Electr. Eng.* **68**(1), 63–75 (2019)
5. Wang, J., et al.: Modelling and parametric design of a pneumatic soft stepper motor. *Int. J. Mech. Sci.* **161–162**(C), 105019–105019 (2019)
6. Jianqiu, L.: Construction of real-time interactive mode-based online course live broadcast teaching platform for physical training. *Int. J. Emerg. Technol. Learn. (IJET)* **13**(06), 73 (2018)
7. Fu, W., Liu, S., Srivastava, G.: Optimization of big data scheduling in social networks. *Entropy* **21**(9), 902 (2019)
8. Liu, S., Bai, W., Zeng, N., et al.: A fast fractal based compression for MRI images. *IEEE Access* **7**, 62412–62420 (2019)
9. Sarbu, V., Avram, M.: A novel approach for assessing the instantaneous flow rate of an external gear pump using 3d printing and computer vision. *IOP Conf. Ser. Mater. Sci. Eng.* **997**(1), 012060 (2020)
10. Chen, Y., Kwok, K.W., Tse, Z.T.H.: Erratum to: an mr-conditional high-torque pneumatic stepper motor for mri-guided and robot-assisted intervention. *Ann. Biomed. Eng.* **45**(10), 1 (2017)
11. Al-Mayyahi, A., Ali, R.S., Thejel, R.H.: Designing driving and control circuits of four-phase variable reluctance stepper motor using fuzzy logic control. *Electr. Eng.* **33**(2), 1–15 (2017)
12. Sánchez-Alvarez, A., Luna-Moreno, D., Hernández-Morales, J.A., et al.: Control of stepper motor rotary stages applied to optical sensing technique using labview. *Optik – Int. J. Light Electron. Optics* **164**(11), 65–71 (2018)
13. Lee, Y., et al.: Nonlinear H_2 control for a nonlinear system with bounded varying parameters: application to pm stepper motors. *IEEE/ASME Trans. Mechatron.* **22**(3), 1349–1359 (2017)
14. Liu, C.H., et al.: Optimal design of a motor-driven three-finger soft robotic gripper. *IEEE/ASME Trans. Mechatron.* **9**, 1–1 (2020)

15. Yuliza, E., Habil, H., Salam, R.A., et al.: Development of a simple single-axis motion table system for testing tilt sensors ☆. *Proc. Eng.* **170**(2), 378–383 (2017)
16. Chen, Y., et al.: Design of multi-line elastic belt conveying control system for knitting machine based on I2C protocol. *IEEE Access* **99**, 1–1 (2020)
17. Heyduk, A., Joostberens, J.: Automatic control of roadheader cutting head speed and load torque. *IOP Conf. Ser. Earth Environ. Sci.* **609**(1), 012081 (2020)
18. Weathersby, E., et al.: Automatic control of prosthetic socket size for people with transtibial amputation: implementation and evaluation. *IEEE Trans. Biomed. Eng.* **99**, 1–1 (2020)
19. De Lima, M.L., Camponogara, E., De Campos, M.C.M.M., et al.: Automatic control of flow gathering networks: a mixed-integer receding horizon control applied to an onshore oilfield. *Control. Eng. Pract.* **86**(MAY), 48–55 (2019)
20. Sui, Q., et al.: Performance of a sequencing-batch membrane bioreactor (SMBR) with an automatic control strategy treating high-strength swine wastewater. *J. Hazard. Mater.* **342**(Jan.15), 210 (2018)