APPLICATION OF AVR POWER AUTOMATIC SINGLE-CHIP MICROCOMPUTER TO THE ELECTROMECHANICAL MEASUREMENT AND CONTROL SYSTEM

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Abstract - The study aims to reduce the production cost and improve the electromechanical management level of enterprises. A switching type reluctance drive system based on Advanced Virtual RISC (Reduced Instruction Set Computer) (AVR) is designed. In addition, the control circuit of the switched reluctance drive (SRD) system needs to be designed. Control circuit design includes the minimum system of the Single Chip Microcomputer (SCM), position sensor circuit, position signal channel, current detection circuit, and current simulation control circuit. Among them, the current simulation control circuit is the most critical hardware. The performance of the designed SRD system is tested through simulation experiments. The results show that when the rated speed is lower than 750 rpm, the rotation multiple is between 1.5 and 2. And when the speed is slow, the matrix output ability will be better. When the speed ratio is 20% more than the rated value, the matrix output ability has 1.32 times the ability of the torque. It can be concluded that the torque output trend and matrix output value conform to the requirements of matrix performance. Combined with the test results of the current waveform, the SRD system based on the AVR microcontroller has excellent control and detection ability. The study provides a technical reference for the design of electromechanical control system and plays an important role in developing the electromechanical measurement and control system.

Keywords: AVR; Single chip microcomputer; Electromechanical measurement and control system; Switching type reluctance drive system.

1. Introduction

With the development of industrialization, various electromechanical equipment is developing rapidly in automation and precision [1,2]. Electromechanical equipment or devices may not work in the operation, which affects the quality of products. Once improperly handled, this may cause production accidents and bring about great damage to the safety of life and property. The electromechanical measurement and control system can help electromechanical equipment or devices complete the measurement task. And the Switched Reluctance Drive (SRD) system is the key to developing electromechanical measurement and control system because of its strong processing ability [3].

The SRD system is rotated under magnetic tension. This is the first step for the research on the reluctance motor [4,5]. The emergence of thyristors makes the Switched Reluctance (SR) motor develop further. Compared with the previous mechanical switches, the semiconductor switch has a fast reaction ability and a large carrying capacity. It is a good material for solving the technical problems of the SR motor. With the continuous development of the SR motor, many scholars have compared the direct current (DC) motor drive system with the SR motor drive system to meet the needs of the electric locomotive drive system. The result shows that the speed regulation performance of the DC motor drive system is better. However, the structure of the DC motor drive system is very complex, the scale is too large, and the cost is higher, resulting in a synchronous increase in maintenance costs. The structure of the SRD system is simple, and the cost is relatively low, thus giving a high evaluation of the SR motor. Therefore, many countries have begun to study the SR motor more deeply [6]. In the process, they have found that most parts of electromechanical equipment have high temperature, high pressure and multiple collisions during operation. With the increase of running time, its performance will decline, affecting its service efficiency and bringing great hidden dangers. As the core processing control chip of the SR motor, the overall performance of digital signal processing (DSP) is better than that of a general Single Chip Microcomputer (SCM). However, the material cost of DSP is higher, and the anti-interference ability is also worse than those of SCM. Therefore, a more complex external anti-interference circuit is needed, and the cost increases further [7].

A speed control system of the SR motor based on Advanced Virtual RISC (Reduced Instruction Set Computer) (AVR) is designed to make the switched reluctance system have the electromechanical measurement and control ability. After the principle of the SR motor is analyzed, the composition of the AVR microcontroller and other hardware configurations are discussed, and the speed control system of the SR motor is obtained. Then, the performance of the system is examined through simulation experiments.

The design of the speed control system of the SR motor has great significance in improving the control and detection ability of the electromechanical measurement and control system.

2. Materials and Methods

2.1 Working Principle of the SR Motor

The electromechanical measurement and control system is SRD, and the reluctance motor is the doubly salient structure of stators and rotors. The SR motor has different phase structures, so the stator and rotor also have different collocation modes [8,9]. Figure 1 shows the cross-section of the structure of the three-phase doubly salient reluctance motor.

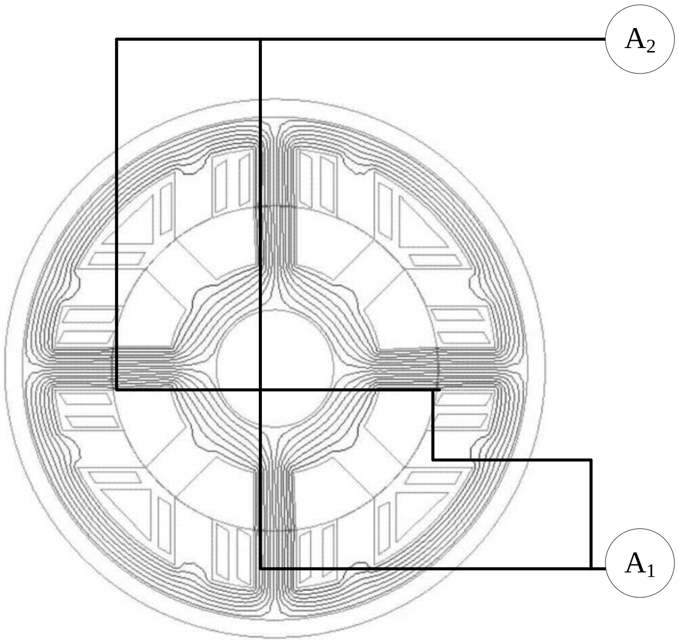


Figure 1: Structure of the three-phase doubly salient reluctance motor

In Figure 1, A1 and A2 represent the direction of conduction. From the cross section of the structure of the three-phase doubly salient reluctance motor, it can be known that there are stators, rotors and coils in the three-phase doubly salient reluctance motor. Independent silicon steel sheets slice stators, rotors and coils. There are 12 poles in the stator, and the coil surrounded on different poles forms a three-phase winding. There are eight poles on the rotor, and they have no relevant winding [10].

The magnetic field distribution of the SR motor is complex, and the previous motor theory and method cannot analyze it. The torque and current of the SR motor can be analyzed by the linear mode method, quasi-linear analysis method, and nonlinear mode method. Among the three analysis methods, the quasi-linear and nonlinear analysis methods are complex and have difficulty deducting the analytical expressions of the motor torque and current. The linear mode method simplifies the analysis conditions and is suitable for deriving the analytical terms of them [11,12].

2.2 Torque Analysis

The input electric energy of windings is W_e, the magnetic energy storage is W_f, and the output mechanical energy is W_m. According to the energy conservation law, the sum of the input electric energy of windings, the magnetic energy storage, and the output mechanical energy is equal if the core loss and rotating mechanical loss in the circuit are neglected, and the equation is:

$$dW_e = dW_f + dW_m \tag{1}$$

The reference direction of the voltage and the induction gesture is the same. According to the law of electromagnetic induction, if the voltage is u and the induction potential is e, the winding mode is expressed as:

$$u = -e = \frac{d\Psi}{dt} \quad (2)$$

In equation (2), Ψ is the winding flux linkage.

The electric energy W_e input by winding is calculated by the end voltage and end current, which can be expressed as:

$$dW_e = uidt \quad (3)$$

If equation (2) is substituted into equation (3), the new equation is as follows:

$$dW_e = id\psi \quad (4)$$

Mechanical energy W_m can be calculated by electromagnetic torque T and angular displacement θ, and the equation is:

$$dW_m = Td\theta \quad (5)$$

Equation (4) is substituted into equations (5) and (1), the obtained equation is:

$$dW_f(\Psi, \theta) = \mathrm{id}\Psi - \mathrm{Td}\theta \quad (6)$$

Equation (6) shows that the magnetic energy storage is represented by independent and state variables in the lossless system θ. The magnetic energy storage is determined by Ψ and θ. When Ψ is a constant, the torque calculation equation can be obtained by equation (6). The equation is:

$$T = -\frac{\partial W_f}{\partial \theta} \quad (7)$$

In equation (7), “-“ is the torque direction.

2.3 Control Strategies of the SR Motor

For the relevant speed and torque of the reference motor, it is hoped that the winding current shouldn’t be too large, the low efficiency of the motor should be overcome in practical application. At this time, the relevant parameters in the motor speed control system need to be adjusted to meet practical application needs. This is called the control method [13,14]. The control method has a significant influence on the speed control system of the SR motor because it determines the difference of the system hardware and software and the difference of the system cost and performance. Therefore, the effectiveness of the control method plays a vital role in the whole system.

Before the system design, the research on the control method becomes critical. The current chopping control, Pulse Width Modulation (PWM) control, and angle control are interpreted below [15].

(1) Angle control method. The current analysis shows that when the power switch device is closed, the winding is added with positive voltage, and the current is established. When the power switch device is disconnected, the winding is added with negative voltage and the operation state of the motor needs to be changed. Generally, it is realized by changing the specific direction between the current and the inductor. Changing the relative position of the current and inductor is also realized by changing the opening and closing the angle of the power device.

(2) Angle optimization. The same speed and torque combination may correspond to different combinations of θ_{on} and θ_{off}. Due to different currents, different motor efficiencies will be generated, so the group of currents with the highest efficiency is always expected. This searching process is the process of angle optimization. At present, angle optimization is realized by a computer and experiment.

(3) Characteristics of angle control. The motor's efficiency in the range of angle control is very high. The peak current is very suitable for high-speed control, and it is not ideal for low-speed control [16,17].

2.4 Current Chopping Control

In the current chopping control method, the power switch device is closed from the pass angle, increasing the winding current. When the specified maximum is reached, the power switch device begins to close after the appointed time, and the current begins to rise from decline. When the current reaches a certain peak, the power switch device is closed, decreasing the current. This cycle is continued until the angle turns off, completing the current chopping control [18].

In terms of electric operation, the turn-on and turn-off angles of the selected power switch device should ensure that the current increases. The output of the pitch is controlled by controlling the peak current. The larger the current peak value is set, the torque output value is more significant, the peak current is smaller, and the torque output value is smaller. When the load is a fixed value, the torque output value increases, and the speed increases further. In other words, the essence of current chopping control is to regulate the peak current. It is similar to the analysis method of the motor braking state.

Current chopping control characteristics. Current chopping control can effectively limit the current growth, making it suitable for use when the current multiplies. Current relay control is relatively slow, so it is ideal for the low real-time situation. In addition, the current relay output is relatively stable. The current chopping control is more suitable for low-speed control in the above points.

PWM has a fast dynamic response. Therefore, it is more suitable for use in high-speed operation, which can effectively limit the winding current and is more suitable in low-speed operation. It should be noted that the low-speed pitch pulsation is relatively large, and it is not ideal for use under large torque pulsation requirements.

2.5 Hardware Design of the Speed Control System of the SR Motor

Mechanical and electrical maintenance is originally unplanned. If a failure occurs, the equipment will be powered off for maintenance, which takes a long time and causes significant damage. Later, the equipment needs regular maintenance. Regular maintenance is conducted according to different types of equipment, and the equipment needs to be regularly checked and maintained. Nowadays, even if the equipment runs well, routine inspection and maintenance must be carried out, resulting in unnecessary maintenance and repair can cause a waste of workforce and financial resources [19]. At present, the diagnosis of electromechanical equipment is mainly focused on the sensor and the vibration signal. In the actual production process, the obtained bearing vibration data are affected by factors, such as strong noise and vibration excitation, which brings extreme nonlinearity and instability of data. The traditional methods of detecting electromechanical equipment are based on human resources. Thus, the failure severity and types are challenging to analyze and detect. The speed control system of the SR motor consists of hardware design and software design. Mechatronics can automatically control and detect the electromechanical equipment and reduce the error caused by manual intervention. The hardware is analyzed and designed below.

If the alternating current (AC) power supply is used, the power circuit covers the rectifier circuit and inverter circuit; if the DC power supply is used, the power circuit only contains the inverter circuit. The speed control system of the SR motor generally uses an AC power supply. The rectifier circuit in the power circuit integrates AC into DC. The rectifier circuit often uses a diode to form an uncontrollable rectifier circuit, which includes a single-phase full-wave rectifier circuit, a three-phase half-wave rectifier circuit, and a three-phase full-wave rectifier circuit. The single-phase full-wave rectifier circuit is often used in the speed control system of the small power SR motor. The three-phase full-wave rectifier circuit is often used in the speed control system of the high power SR motor three-phase half-wave rectifier circuit is used between the above power range. 380V AC power supply is used, and the power is 21kW. The rectifier circuit uses a three-phase full-wave rectifier circuit, and its structure is shown in Figure 2.

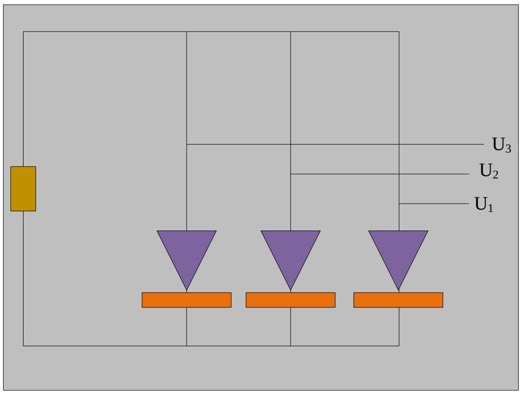


Figure 2: Structure of the three-phase full-wave rectifier circuit

In Figure 2, U1, U2 and U3 represent different currents. In the three-phase full-wave rectifier circuit, the rectifier bridge module is composed of diodes used in the rectifier. The electrolytic capacitor is used in filtering. The other capacitor is used in high-frequency bypass. This is to reduce the high-frequency consumption of electrolytic capacitors.

The phase current needs to maintain the phase sequence, and a certain turn-off time is needed to make the speed control system of the SR motor work normally. An inverter circuit should do this work. The inverter circuit is powered by AC rectifier power supply, and a pulse current should be periodically input to operate the SRD system. The speed control system of the SR motor is loop-locked, which requires the replacement of the “phase”. When the motor is running, it is necessary to prevent the over-current time, so that the braking torque is obtained, affecting the efficiency of the system. Therefore, various circuit power schemes of the speed control system of the SR motor are classified by commutation and over-current. The topology of the inverter circuit falls into the double winding, double switch and capacitor energy storage according to the difference of continuous currents.

2.6 Minimal System Design of the AVR Microcontroller

In addition to the design of the power circuit, the control circuit of the SR motor drive system needs to be designed. The control circuit design includes the AVR microcontroller minimum system, position sensor circuit, position signal channel, current detection circuit, speed, and current analog control circuit. Among them, the design of the speed and current analog control circuit is the most critical.

SCM can meet regular work needs, and it must have a relatively complete minimum system. The elements of the minimum design of SCM are in Figure 3.

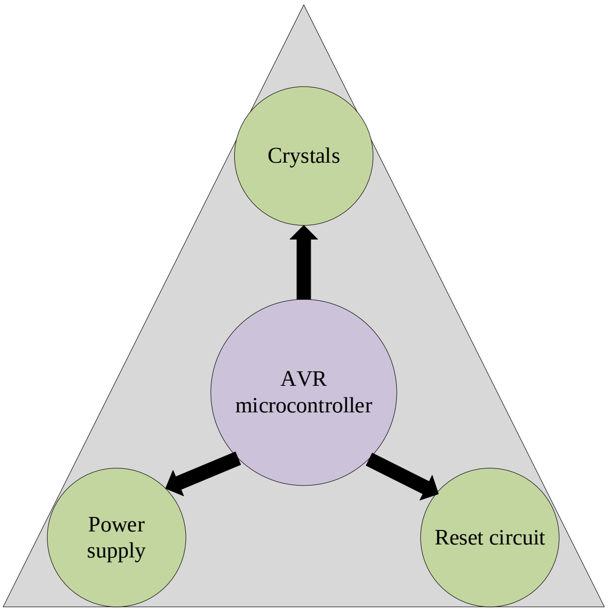
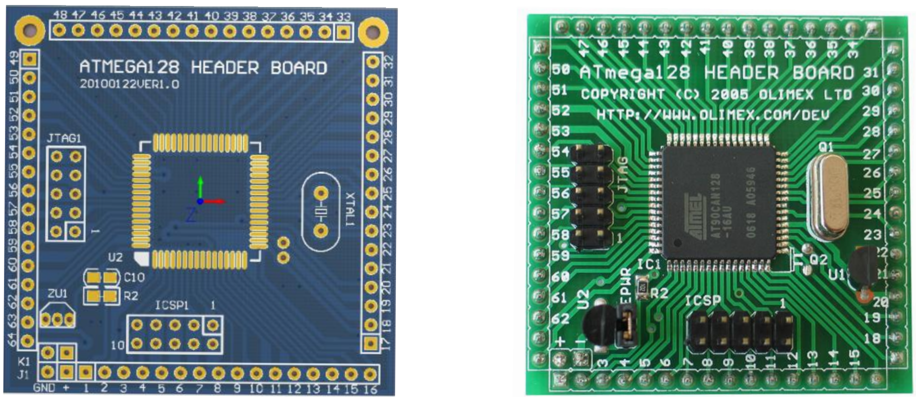


Figure 3: Elements of the minimum system of SCM

In the traditional 51 SCM, the reset function and crystal vibration are generally embedded in AVR-SCM, so it is not necessary to add additional circuits. The power supply for AVR microcontroller is only needed to perform effective work. When the oscillation frequency is adjusted, the fuse position can be used to adjust. Other reset circuits and crystal oscillator circuits can also be added in different working environments.

The minimum system of two AVR automatic microcontrollers is shown in Figure 4.



(a) (b)

Figure 4: The minimum system of the AVR microcontroller (a) The minimum system of ATmega128, b) The minimum system of AVR-H128 version)

The ATmega128 internal reset and crystal oscillator are used in this design, and the supply power is 5V. Position closed loop is the key to distinguishing the speed control system of the SR motor from general electromechanical drive systems.

The position sensor determines the position of the rotor relative to the stator and provides useful data information for conducting each phase winding of the motor. Only the correct position data can make the winding of each phase be turned on and off without errors, completing the adjustment of the system.

The design uses the photoelectric position sensor, and its composition is shown in Figure 5.

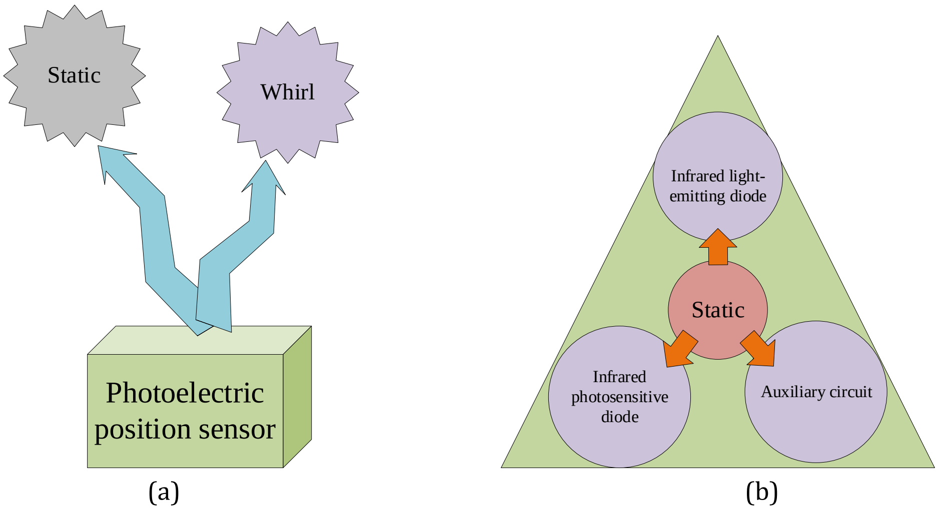


Figure 5: Composition of the photoelectric position sensor (a) Elements of the macroscopic composition, b) Static elements of the macroscopic composition)

The control board provides electricity to the sensor, and the three-position signals output by the sensor are transmitted to the position signal channel circuit of the control board. The working principle of the position sensor is shown in Figure 6.

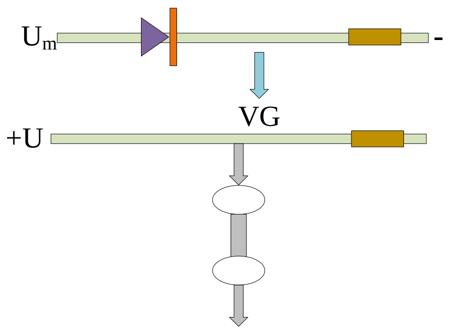


Figure 6: Principle of the position sensor

In Figure 6, VG is the voltage, U_m is the control board, and +U is the sensor. There is a certain correlation between stator and rotor salient pole and phase inductance.

The three-phase sensor signal corresponds to the increase of the phase inductance, so that the phase that needs to be adjusted is known. The phase can be turned on and off in a certain period to generate positive electric torque and braking torque. In conduction, different phase current waveforms are formed, and the various working conditions of the SR motor system are detected.

2.7 Simulation Experiment

The prototype of the speed control system of the SR motor needs to be debugged when its performance is tested and verified.

The detection system uses a 22kw switched reluctance controller. The test needs an SR motor, asynchronous motor variable frequency load, torque meter, dynamometer and oscilloscope. The rated power is 22kw, the rated speed is 750rpm, and the rated torque is 280N•m. The components of the detection and test system are shown in Figure 7.

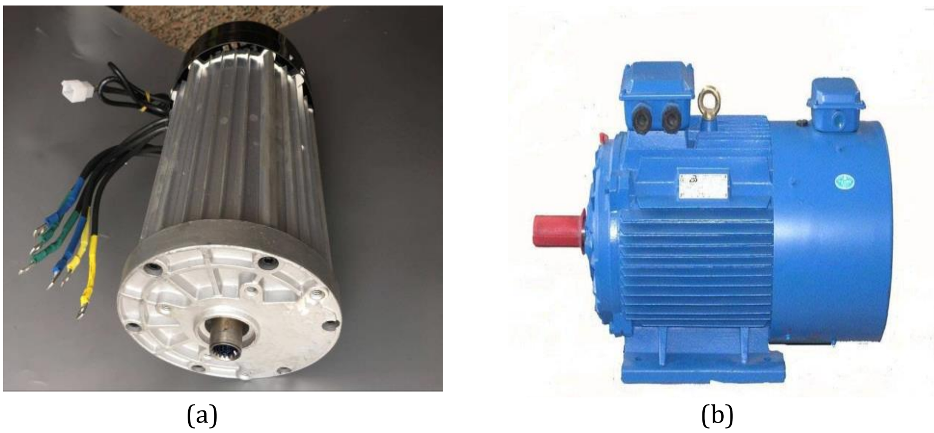


Figure 7: Components of the detection and testing system (a) SR motor, (b) Variable frequency load of the induction motor

During the detection, a series of experiments are carried out, and the current waveform and torque output of the speed control system of the SR motor are systematically detected.

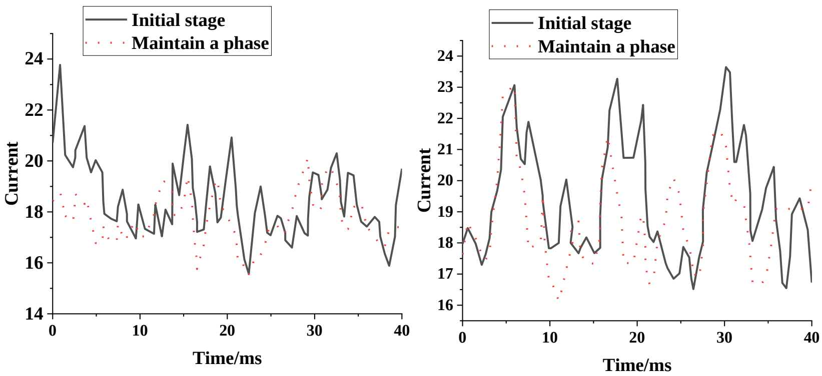
3. Results

3.1 Test Results of the Current Waveform

When the motor is in a low-speed state and high-speed state, the detected current waveform is shown in Figure 8.

When the motor is in a low state, there are an initial stage and the freewheeling stage, and the top of the current is relatively flat. The reason for this is that the motor's output power is relatively small, and the required current is also relatively small. A small current can meet the requirement of the motor. At this time, the change of the phase inductance has little effect on the current waveform.

When the motor is in a high-speed state, there is still an initial stage and a continuation stage, which requires a relatively large output current in a short time. When the current output is rather large, the change of phase inductance significantly impacts the current waveform.



(a) (b)

Figure 8: Current waveforms (a) Low-speed current waveform, b) High-speed current waveform)

3.2 Results of Matrix Outputs

ASR motor with a torque of 280N·m is used to test the torque output value, so that the torque output ability of the SRD system is tested. The test results are shown in Figure 9.

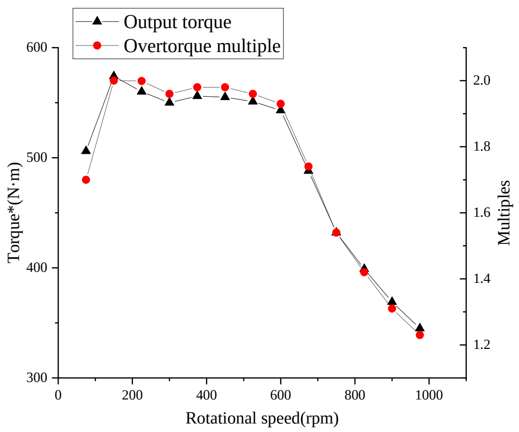


Figure 9: Test results of matrix outputs

Figure 9 shows that when the rated speed is lower than 750rpm, the rotation ratio is between 1.5 and 2, and the matrix output capacity will be better at low speed. When the speed ratio is 20% more than the rated value, the rotation ratio has 1.32 times the ability of the torque. It can be concluded that the torque output trend and matrix output value meet the requirements of the matrix.

Combined with the test results of the current waveform, the speed control system of the SR motor based on the AVR microcontroller has excellent control and detection performance, which provides a good technical reference for the design of the electromechanical control system.

4. Conclusions

With the development of industrialization, various mechanical and electrical equipment is developing rapidly in automation and precision. Some electromechanical equipment or devices may have failures in operation under unpredictable conditions, which often leads to a decline in the quality of products. Once improperly handled, the failure of the equipment may cause production accidents and significant damage to people's lives and property.

The electromechanical automatic measurement and control system can complete object measurement and task control throughout the operation process. Therefore, the optimization design of the electromechanical automated control system is discussed. In addition to the design of the power circuit, the control circuit of the SR motor drive system needs to be designed. It mainly includes the minimum system of SCM, position sensor circuit, position signal channel, current detection circuit, speed, and current simulation control circuit. The speed and current simulation control circuit is the most critical among them. On this basis, a speed control system of the SR motor based on AVR-SCM is designed, and its performance is tested through simulation experiments. The research results show that the designed speed control system of the SR motor has excellent performance, and it has the two abilities to conduct operation and detection in the operation system. The shortcoming is that the software of the SRD system is not optimized. In the future, more detailed optimization of the relevant software is needed to improve the control and detection ability of the system.

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References

[1] Peng X., Jia M., He L., et al. (2018) Fuzzy sliding mode control based on longitudinal force estimation for electro-mechanical braking systems using BLDC motor. CES Transactions on Electrical Machines and Systems, 2(1), 142-151.

[2] Chae J., Kim Y. H. (2017) Performance of the Autoregressive Method in Long-term Prediction of Sunspot Number. Journal of Korean Astronomical Society, 50(2), 21-27.

[3] Zhang W., Du Y., Taketoshi Y., et al. (2018) SamEn-SVR: Using Sample Entropy and Support Vector Regression for Bug Number Prediction. Iet Software, 12(3), 183-189.

[4] Dong W., Yang Z., Yang F., et al. (2017) Nonlinear-drifted Brownian Motion with Multiple Hidden States for Remaining Useful Life Prediction of Rechargeable Batteries. Mechanical Systems and Signal Processing, 93, 531-544.

[5] Guo G., Fall M. (2021) Advances in Modelling of Hydro-mechanical Processes in Gas Migration within Saturated Bentonite: A State-of-art Review. Engineering Geology, 287(3), 106123.

[6] Pethaperumal H., Sivakumar N. (2017) Effectiveness of Mechanical Material Handling Equipment Safety in Construction Sites for Operation Safety and Environmental Health. International Journal of Applied Environmental Sciences, 12(3), 541-552.

[7] Chen X., Zhang L., Liu T., et al. (2019) Research on Deep Learning in the Field of Mechanical Equipment Fault Diagnosis Image Quality. Journal of Visual Communication and Image Representation, 62(JUL.), 402-409.

[8] Ding P., Jia M., Yan X. (2021) Stationary Subspaces-vector Autoregressive with Exogenous Terms Methodology for Degradation Trend Estimation of Rolling and Slewing Bearings. Mechanical Systems and Signal Processing, 150, 107293.

[9] Guo R., Wang J., Zhang N., et al. (2018) State Prediction for the Actuators of Civil Aircraft based on a Fusion Framework of Relevance Vector Machine and Autoregressive Integrated Moving Average. Proceedings of the Institution of Mechanical Engineers, 232(5), 622-434.

[10] Cinar Y. G., Mirisaee H., Goswami P., et al. (2018) Period-aware Content Attention RNNs for Time Series Forecasting with Missing Values. Neurocomputing, 312(OCT.27), 177-186.

[11] Abdel-Nasser M., Mahmoud K. (2019) Accurate Photovoltaic Power Forecasting Models Using Deep LSTM-RNN. Neural Comput & Applic, 31, 2727-2740.

[12] Sahoo B. B., Jha R., Singh A., et al. (2019) Long Short-term Memory (LSTM) Recurrent Neural Network for Low-flow Hydrological Time Series Forecasting. Acta Geophys, 67, 1471-1481.

[13] Abdulkarim S. A., Engelbrecht A. P. (2019) Time Series Forecasting Using Neural Networks: Are Recurrent Connections Necessary[J]. Neural Process Lett, 50, 2763-2795.

[14] Affonso F., Dias T. M. R., and Pinto A. L. (2021) Financial Times Series Forecasting of Clustered Stocks. Mobile Netw Appl, 26, 256-265.

[15] Rhif M., Abbes A. B., Martinez B., et al. (2020) A Deep Learning Approach for Forecasting Non-stationary Big Remote Sensing Time Series. Arabian Journal of Geosciences, 13(22), 1-11.

[16] Kumar J., Goomer R., Singh A. K. (2018) Long Short Term Memory Recurrent Neural Network (LSTM-RNN) Based Workload Forecasting Model For Cloud Datacenters. Procedia Computer Science, 125, 676-682.

[17] Ekinci S., Hekimoğlu B. (2019) Improved kidney-inspired algorithm approach for tuning of PID controller in AVR system. IEEE Access, 7, 39935-39947.

[18] Khosravi-Charmi M., Amraee T. (2018) Wide area damping of electromechanical low frequency oscillations using phasor measurement data. International Journal of Electrical Power & Energy Systems, 99, 183-191.

[19] Bingul Z., Karahan O. (2018) A novel performance criterion approach to optimum design of PID controller using cuckoo search algorithm for AVR system. Journal of the Franklin Institute, 355(13), 5534-5559.