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Design and Research of Intelligent Valve Control

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Abstract

The design and research of intelligent valve control system aims to improve the efficiency and accuracy of fluid control in industrial process automation. By integrating advanced sensing technology, communication protocols and intelligent algorithms, the precise control of valve position, pressure and flow rate is achieved. STM32 controller and a variety of sensors are used in the system to realize real-time monitoring and feedback control of valve status. The control strategy based on PID algorithm enables the valve to maintain stable operating performance under complex working conditions. In addition, the safety and reliability of the system are also considered, and the robustness of the system is improved by redundant design and fault detection mechanism. The experimental results show that the designed intelligent valve control system has significant advantages in improving response speed, control precision and energy efficiency, and has a wide range of industrial application prospects.

Keywords

Intelligent Valve Control; PID Control; Embedded Controller; STM32.

1. Introduction

With the continuous improvement of industrial modernization technology, the scale of domestic industrial construction is also expanding, and the characteristics of the era of integration of modern science and technology in the field of industrial development are becoming more and more significant. In the transportation of oil, natural gas and other resources, complex and cumbersome pipeline control equipment will be used, among which electric actuators play an important role. As the terminal component in the intelligent control system, the electric actuator plays a pivotal role in the automatic control system. It replaces the manual drive of the relevant components and is the core of the automated production process.

Electric actuator is currently in the development period and rising period, complete product specifications, high control precision, compact mechanical structure, with a variety of protection functions, strong applicability, stable performance, explosion-proof safety, mechanical installation, parameter debugging, control operation, convenient maintenance, is a very promising electric device. They will be more and more used in industrial production automation process control.In metallurgy, chemical industry, energy, oil field industry and other industrial control, the use of electric actuators has become more and more common, and the requirements for its function and use have become more stringent. Oil field operations usually involve a large number of mechanical operations and equipment with relatively high operating costs. The design of new intelligent electric actuators can reduce manual intervention and improve work efficiency through automation and intelligent control, thus reducing operating costs and reducing production costs in the field. There are always dangerous and high-risk situations in oil field operations, such as explosions, leaks, etc. Research on intelligent electric actuators can reduce the need for personnel to contact dangerous environments through remote monitoring and automatic control, improve the safety of operations, and reduce the possibility of accidents. New intelligent electric actuators can achieve high precision and high efficiency operations, thereby improving oil field production and production efficiency.

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Automation can operate without interruption, reducing downtime and increasing production capacity. In independent research and development, our goal is to actively respond to the impact of the international situation. Although foreign products have significant competitive advantages, we are determined to ensure the independent control of core technologies to avoid the impact of technical barriers on us. Such efforts will help safeguard technological independence, reduce dependence on instability in international markets and provide solid support for our country's indigenous innovation.

2. Research Trends at Home and Abroad

Automatic actuator research field, our country in the starting stage is far behind the western countries, it was started in the 1960s through the study of the Soviet Union's electric actuator to imitate, the most representative is DKZ type straight stroke electric actuator, which is the first independent research and development of electric executive structure in our country . Since the 1980s, two types of contactless DKJ Angle stroke and DKZ straight stroke have been developed. With the application and development of modern industrial control computer management, most products in our country have also realized intelligence, but compared with the international advanced intelligent electric actuators, there are still problems such as backward control mode, low reliability, cannot connect to the network, and cannot be remotely controlled. At this stage or more dependent on foreign intelligent products. Compared with the intelligent electric actuators imported from developed industrial countries, there are still problems such as backward control mode, low reliability, inability to connect to the network and remote control. At this stage or more dependent on foreign intelligent products. Compared with the advanced technology of developed industrial countries, domestic electric actuators still have shortcomings. For example, the control accuracy is low, the control method is simple, usually only manual, 4-20mA, one or several switching quantities; The human-computer interaction is not friendly enough, and the parameters that can be set often take users too much time to get familiar with a device.

3. Integrated Design

This topic aims to design a new intelligent electric actuator based on STM32F407 and electronic technology, which is an advanced mechatronic product. It is composed of motor, worm gear and worm drive mechanism, and STM32 as the core high-end large scale integrated circuit. It has a watchdog and can diagnose itself without restarting. FreeRTOS operating system is used to manage the multi-task execution, which improves the maintainability and reliability of the embedded system. Motor is the core of the electric execution device, to use a specially designed low inertia, high torque motor, start can quickly reach the peak torque, embedded temperature protection device can prevent motor burn. Using the latest EEPROM memory, the set parameters are saved forever, and the data will not be lost when the power is returned after the operation parameter fails. Data logging, historical data storage, especially failure data playback, black box function. The motor is controlled by PID algorithm, which is a powerful method to achieve accurate control of the motor. Setter debugging, do not need to open the end cover, HD LCD display, good visibility. The power supply adopts 380V, 50Hz AC power supply, and the power control module includes a motor interlocking invertible contactor (frequent regulation type actuator is a non-contact motor commutator). The internal control power supply is taken from the two phases of the input power supply, which is used as an internal control circuit after

transformer step-down. There is also a separate rated power supply to power the actuator remote control circuit. The power transformer is designed for split coil, double insulation, and

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includes short circuit and overload protection. And the remote communication module to upload some basic information of the electric actuator to the server platform.

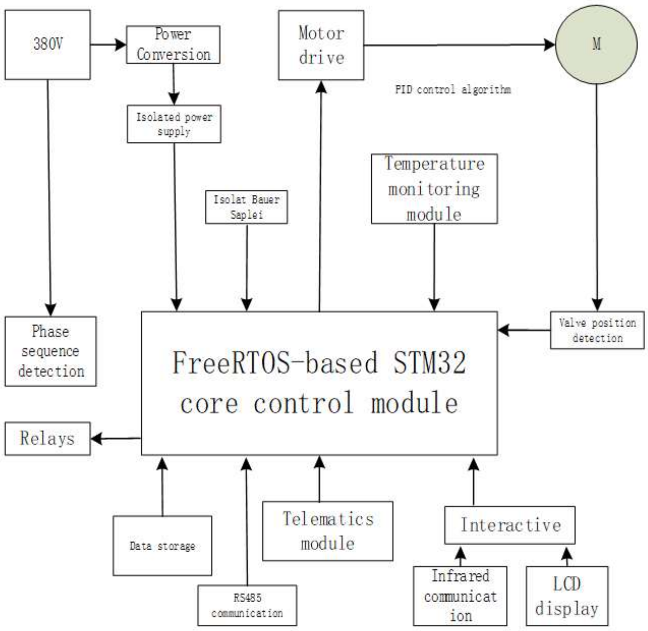

Figure 1. Overall structure

For the control of electric actuator, it can be divided into remote control and local control. Remote control is divided into remote pulse control, analog control, interlocking control, condition control and bus control. Remote pulse control can be set to hold or point and step control. The remote control input adopts photoelectric isolation interface, which can resist 2kV high voltage.

Remote analog control allows proportional control of valve opening.

The working principle of the structure is that the rotation of the motor directly drives the worm drive through the joint shaft mechanism, the worm drive the worm wheel rotation, and then drive the output shaft rotation through the clutch. When the switch handle is in the manual position, the clutch moves up, the worm gear is disconnected from the handwheel, and the handwheel is rotated to directly drive the output shaft. Electric operation is always preferred unless the handle is locked in the manual gear. When the output shaft rotates, a pair of bevel gears are driven to rotate, and the valve position is detected by the absolute encoder.

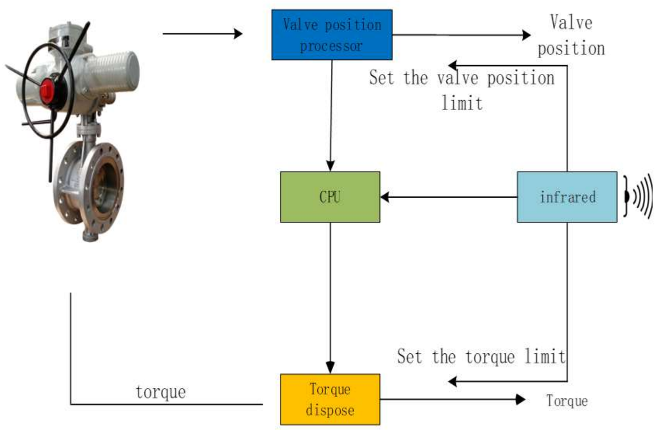

Figure 2. Working principle

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4. Introduction to the Algorithm

PID algorithm is a commonly used algorithm in closed-loop control systems. PID is the acronym of Proportion, Integral and Differential respectively. It is a closed-loop control algorithm that combines proportion, integration and differentiation.

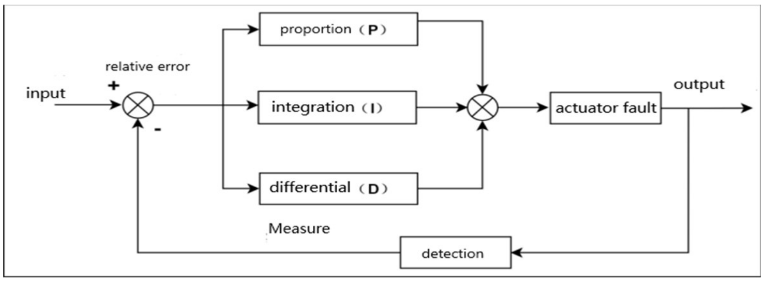

Figure 3. PID

We calculate the deviation between the input target value and the actual output value, and then input the calculation results into the PID control algorithm. After the operation of proportion, integration and differentiation, the output of the operation acts on the actuator, so that the actual value of the system is gradually close to the target value.

4.1. Proportional Component

The proportional link can reflect the deviation signal of the control system in proportion, that is, the output is proportional to the input deviation, and can be used to reduce the deviation of the system. The formula for this step is as follows:

$$\mu = K_p \cdot e \tag{1}$$

μ is output K_p is the scaling factor and e is the bias.Let's take the example of greenhouse temperature control to understand this formula. Suppose we now need to adjust the temperature in the shack to 30°C, while the actual temperature is 10°C, the deviation e=20 at this time, according to the formula of the proportion link, when e is determined, the larger K_p is, the larger the output μ is, that is, the greater the adjustment strength of the temperature control system, so that the target temperature can be reached faster. However, when K_p is determined, a larger deviation e leads to a larger output μ. It can be seen that in the proportion link, the larger the proportion coefficient K_p and the deviation e, the shorter the time for the system to eliminate the deviation.

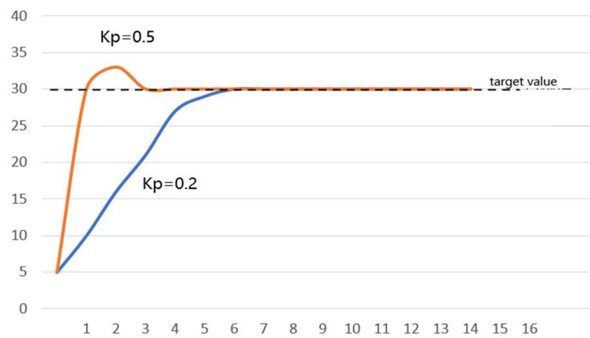

Figure 4. K_p effect picture

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When the value of K_p is larger, the time for the corresponding orange curve to reach the target value is shorter. At the same time, the orange curve appears overshoot and oscillation in a certain range, which will reduce the stability of the system. Therefore, when setting the scale coefficient, the larger is not the better, but the time to eliminate the deviation and the stability of the whole system should be taken into account.

However, in practical applications, if only the proportional link is controlled, it may bring a problem to the system: static error. Static error refers to the deviation between the target value and the measured value when the system control process tends to be stable.

Let's take the example of greenhouse temperature control to understand what is a static error: Suppose we now need to adjust the temperature in the shed to 30°C, while the actual temperature is 25°C. At this time, the deviation e=5 and K_p is a fixed value. If the output at this time can heat up 5°C in half an hour, and the external temperature difference can cool down 5°C in half an hour, that is to say, The effect of the output μ is just offset by the external influence, which causes the bias to persist.

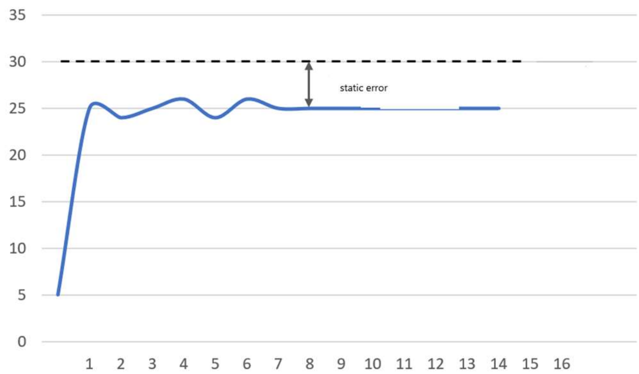

Figure 5. static error

One might think that we could increase the output by increasing K_p to eliminate the bias. In practice, this method is very limited, because we cannot determine the size of the bias, it is changing in real time, if we set K_p too large, overshoot and oscillation will be introduced, making the stability of the whole system worse. Therefore, in order to eliminate the static error, we introduce the integration link.

4.2. Integration Element

The integration link can integrate the deviation e. As long as there is a deviation, the integration link will continue to function, mainly used to eliminate the static error and improve the indifference degree of the system. After introducing the integral link, the formula of proportion + integral link is as follows.

$$\mu = K_p \cdot e + K_i \cdot \sum e \tag{2}$$

Where μ is the output, e is the bias,$\sum e$ is Cumulative deviation.K_p is proportionality coefficient and K_i is Coefficient of integration.

We still take the example of greenhouse temperature control to understand the role of the integral link. Suppose now that the proportional link of the temperature control system is canceled, there is a static error of 5℃. At this time, the deviation exists, and the integral link will always accumulate the deviation to increase the output, thereby eliminating the static error. From the above formula, it can be known that when the integration coefficient K_i or the cumulative deviation is larger, the output is larger and the time for the system to eliminate the static error is shorter.

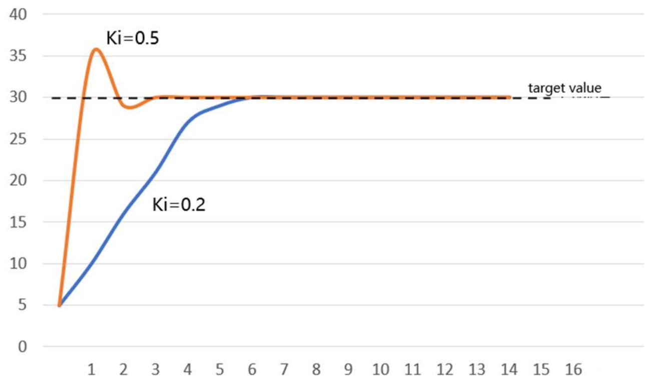

Figure 6. Phenomenon of overshoot

When the value of K_ii is larger, the time for the corresponding orange curve to reach the target value is shorter. At the same time, the orange curve has a certain amplitude of overshoot and oscillation, which will reduce the stability of the system. Therefore, when setting the integration coefficient, it is not the bigger the better, but the time to eliminate the static error and the stability of the whole system should be taken into account. We said earlier that as long as there is a bias in the system, the integration process will accumulate the bias. When the system deviation is 0, it means that the target value has been reached, and the cumulative deviation is no longer changed, but the integration link is still playing a role (often the largest role at this time), which is easy to produce overshoot phenomenon. Therefore, we need to introduce the differential link to weaken the output in advance and suppress the occurrence of overshoot.

4.3. Differentiation Element

The differential link can reflect the variation trend of the deviation, and make corresponding control in advance according to the variation of the deviation to reduce the overshoot and overcome the oscillation. After introducing the differential link, the formula of proportion + integral + differential link is as follows.

$$\mu_k = K_p \cdot e_k + K_i \cdot \sum_{j=0}^{k} e_j + K_d(e_k - e_{k-1}) \tag{3}$$

We still take the example of greenhouse temperature control to understand the role of differential links. Assuming that the target temperature of the temperature control system is 30℃, there is a deviation of 15℃ at 8 am. After a period of adjustment, by 9 am, the deviation has been reduced to 5℃, and the change of deviation = deviation at 9 o 'clock (KTH time) - deviation at 8 o 'clock (k-1 time) = -10. Combined with the above formula, it can be known that, At this point, the differential link will weaken the effect of the proportional and integral links and reduce the output to suppress overshoot.

In the actual application, not every system needs the three links of PID to participate in the control, some systems only need the proportion link or integral link can be controlled very well, in addition, the PID coefficient of each system is not universal, which needs to be set according to the actual situation

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5. Discrete Formula of PID Algorithm

5.1. Position-based PID Formula

$$\mu_k = K_p \cdot e_k + K_i \cdot \sum_{j=0}^{k} e_j + K_d(e_k - e_{k-1}) \quad (4)$$

The discrete PID formula we obtained in the previous subsection is called positional or full PID formula. The calculation of this formula requires the participation of all control quantities, and each output of this formula is related to the past state.

5.2. Incremental PID Formula

From the position-based PID formula, we can derive the incremental PID formula in two steps: In the first step, substituting k = k-1 into the position-based PID formula, we obtain:

$$\mu_{k-1} = K_p \cdot e_{k-1} + K_i \cdot \sum_{j=0}^{k-1} e_j + K_d(e_{k-1} - e_{k-2}) \quad (5)$$

In the second step, from μ_k-μ_{k-1}:

$$\Delta\mu_k = K_p \cdot (e_k - e_{k-1}) + K_i \cdot e_k + K_d(e_k - 2e_{k-1} - e_{k-2}) \quad (6)$$

This concludes the derivation of the incremental PID approach. As can be seen from the formula, the calculation of incremental PID does not need to accumulate the deviation all the time, and its output has a lot to do with the deviation of nearly three times.

Note: The incremental PID formula outputs only the increment of the control quantity. Let's take an example to understand this statement: suppose the actual speed of the motor is 50RPM, and now we want to accelerate it to 60RPM. If we use a position-based PID, the system will directly output the control quantity (duty cycle) corresponding to 60RPM. If we use incremental PID, the system will speed up the output by 10RPM corresponding to the control amount (duty cycle), in which case we also need to add the output of (50RPM).

5.3. Relative Merits

① Position-based PID: Advantages: Position-based PID is a non-recursive algorithm with integral action, which is suitable for objects without integral parts.

Disadvantages: full calculation, calculation error greatly affected; It needs to accumulate the deviation, which is computationally expensive.

② Incremental: Advantages: only output incremental, calculation error less influence; There is no need for cumulative deviation, less computation, and relatively good real-time performance.

Disadvantages: Large integral truncation effect, steady state error.

6. Conclusion

The design of intelligent valve control system aims to solve the problems of low efficiency, insufficient accuracy and response lag in traditional valve control, so as to improve the overall control performance in industrial automation processes. By introducing advanced sensor technology, embedded controller and intelligent algorithm, the system realizes the real-time monitoring and dynamic adjustment of the valve position, flow rate and pressure, and ensures the stable operation under various complex conditions.

In this study, not only the control accuracy has been significantly improved, but also the system has stronger adaptability in the face of working condition changes through the combination of

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fuzzy logic and PID control. This intelligent control strategy effectively reduces the need for human intervention and reduces the difficulty of operation and the risk of misoperation. In addition, the redundant design and fault detection mechanism of the system further improve its safety and reliability, ensuring that it can still maintain efficient and stable operation under extreme working conditions.

The research results show that the intelligent valve control system has significant advantages in improving energy efficiency, reducing operating costs and prolonging the life of equipment, and can effectively solve the bottleneck problem that is difficult to overcome by traditional control methods. Through the extensive adaptability and flexibility design for industrial application environment, the system shows excellent market prospects and application potential.

In the future, with the continuous development of industrial automation technology, intelligent valve control system will become an important force to promote the intelligent transformation of industrial processes, and it will play a key role in improving production efficiency, optimizing resource allocation and realizing green manufacturing.

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