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Improved PID Algorithm-intelligent Detection System of Tightening Machine

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Abstract: - As the level of automation in manufacturing industry continues to improve, intelligent tightening technology is widely used in many fields. Research on torque, force and angle control technology for tightening machines focuses on designing sensitive detection systems, constructing control models and implementing accurate control of tightening parameters. This article proposes an optimized PID algorithm to improve tightening accuracy and stability. At the same time, an intelligent tightening machine monitoring system will be designed and developed to achieve online monitoring and control, ensuring tightening quality and stability. The system will use the latest technologies, including big data, cloud computing and artificial intelligence, to further optimize the tightening effect. The overshoot of PID control optimized by PSO-GA hybrid algorithm is 8.367% , which is far less than that of PID control alone, it is shown that the PSO-GA hybrid algorithm has higher accuracy and better robustness.

Keywords: Detection System, PID Control, PSO-GA Algorithm, Torque Sensor.

I. INTRODUCTION

The operation requirements of construction machinery not only involve completing specified work processes but also ensuring strength and reliability meet the required standards. However, due to the characteristics of the tightening machine, all components need to work together during motion, and each component experiences different forces. Therefore, it is difficult to accurately analyze the dynamics of the mechanical arm using traditional methods. Many scholars have conducted research on engineering machinery arms [1], including kinematic analysis, dynamic analysis, and optimization design of control systems such as RBF algorithm PID control, particle swarm optimization (PSO) algorithm PID control, BP neural network PID control, and so on. However, in order to improve the accuracy and robustness of PID control, this article proposes the PSO-GA hybrid algorithm to optimize the tuning of PID control [1-3]. The analysis results aim to provide references for future research on tightening machines.

II. DESIGN A SENSITIVE BENDING MOMENT DETECTION SYSTEM

The overall design concept is to allow the components in a measurement facility to be in a movable state. Under the influence of force or torque, these components will produce displacements. By measuring these displacements and analyzing other parameters, the magnitude of the torque generated at the location of the measurement facility can be determined. From the perspective of the torque calculation formula, M=Fl, where F represents the tangential force acting at the point. However, for the robot wrist force measurement sensor, it is important to note that the wrist force itself has six degrees of freedom. This has various implications on the sensor, leading to multiple forms of movement. While the torque calculation formula is correct, it entails consideration of numerous factors including the force parameters acting on each degree of freedom and the torque length parameters [4].

Additionally, considering that wrist force and torque data for robots are generally small, and the sensor size is also small, attention must be given to the processing and analysis of measurement results. Adjusting the force length parameters and proportional configuration may be considered to enhance the precision of the actual measurement results. Analysis of these parameters ultimately determines the overall sensor design as shown in Figure 1.

In this design, the sensor is divided into two parts: the inner ring and the outer ring. The inner ring is movable while the outer ring is fixed. An LED bulb is located in the middle of the inner ring, corresponding to slits intersecting in the horizontal and vertical directions. PSDs are placed on the outer ring corresponding to the direction of the slits. The spacing between the inner and outer rings is determined according to practical circumstances. Theoretically, the spacing parameter does not affect the measurement results. When the sensor is subjected to wrist force or torque, the inner ring will experience displacement, which will be detected by the PSD. This displacement will be measured and calculated to obtain the final results [5].

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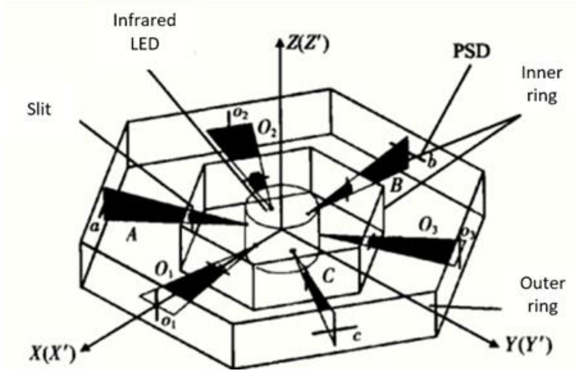

Figure 1: The Working Form of the Torque Sensor

A. Configuration of Related Components

All types of components must be kept in a stable operating state. In addition, for the active components in the sensor, it is necessary to ensure that the relationship between the displacement of the moving block and the force is fixed, so the connecting component between the moving component and the fixed component is a rectangular spring, because this type of spring has a better linear relationship [6]. As for the narrow gap of the moving ring, because it is necessary to ensure that the light lines forming the path in the sensor can be received by the PSD, the size of the gap must be strictly controlled, requiring that the spacing be maintained within a certain range during gap processing, so that the entire system's infrared light can be received by the PSD and the measurement results can be transmitted to the computer system. The current wrist force and torque values are calculated by the software through the use of relevant codes and instructions.

B. Various Components Connections

The connection of various components is, in fact, the simplest task in the entire assembly and design process, and all facilities must ensure a tight connection with the fixed components. The active ring can move under force, and due to the demands on the device posed by multiple degrees of freedom, the stability of the equipment decreases. Therefore, it is necessary to ensure that the rectangular spring of the component can be in a high-strength connection state with the fixed ring, and the connection between the moving ring and the rectangular spring must also be guaranteed. Another key connection is the strength of the connection between the PSD components and the related cables in the entire sensor [7]. It is required to increase the welding strength of the cables during the operation of the entire system, so that all signals can be transmitted to the computer system in a timely manner. At the same time, the computer system must be able to recognize such data through a dedicated interface. In addition, since the sensor is to be set at a relevant position of the robot, usually at the robot's wrist, the fixed ring of the sensor must be connected to the fixed facilities of the robot's wrist with high strength. Only under this condition can the sensor better obtain the measurement parameters of wrist force and torque [8].

III. DESIGN METHODS FOR FLEXIBLE WRIST FORCE AND TORQUE SENSORS

A. Software Design

In the design process of the software system, it is required to understand various data and perform detailed calculations of torque and wrist force based on the developed theoretical mechanics and material mechanics knowledge. In specific work, it is necessary to analyze the parameters required for calculations based on an understanding of the equations for wrist force and torque calculations. The items to be analyzed include the deformation of the spring and the external forces exerted on a certain point by the fixed components during operation. Attention should be paid to the relationship between the external forces borne by the sensor, the resultant force, and the tangential force. Based on this, the calculation of the tangential force borne by that point can be completed to understand the torque it bears [9]. After completing the construction and optimization of the mathematical model, it needs to be integrated into the corresponding calculation software, especially through the analysis of various acquired parameters, and the final calculation results are displayed through the computer's human-computer interaction interface.

B. Hardware Design

1) Hardware system flowchart

In the design of the hardware system, the first step is to determine the operational flowchart of the hardware architecture. Based on the analysis of the sensor signal acquisition process, this article ultimately developed the hardware operational flowchart as shown in Figure 2 [10].

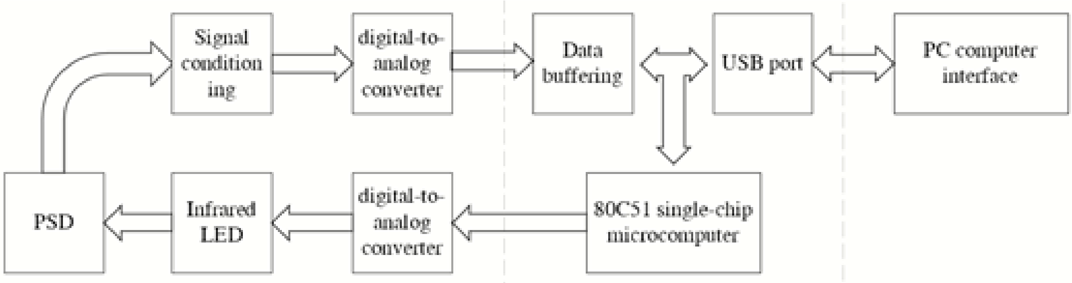

Figure 2: Sensor Hardware System Operation Process

The entire system actually operates in a feedback control mode. Through the micro controller's measurement and comparison of relevant parameters, it achieves an understanding of the accuracy and quality of the current analysis signal. Based on this, it further processes various types of data through signal adjustment and conversion facilities [11]. The high-precision data obtained is then input into the computer's data receiving port. Simultaneously, the specialized software installed on the computer can autonomously explore the actual accuracy of various parameters. When discrepancies are found between the measured parameters and the allowable error range of the calculations, the information is fed back into the measurement system.

2) Assembly of various components

In fact, when choosing the overall system operation concept and operation mode, the reasonable matching of components can be completed. In the system selected in this article, the most important matching content is the matching mode between computer system-related parameter acquisition components and the data transmission system. The method is to integrate various facilities such as resistors and inductors into the same operating system in the form of a dedicated circuit board, so that the system can complete the acquisition, measurement, and analysis of various parameters [12]. In addition, for the already built sensors, the PSD needs to be connected to the corresponding facilities, which can ensure that all six PSDs can provide their current measurement parameters to the already built circuit board in the case of complex forces. The measurement system inputs the obtained parameters to the PC through the application of relevant models, especially to calculate the overall force situation that the sensors are subjected to. In fact, since the single chip microcomputer can simultaneously analyze the parameters of multiple PSDs and issue corresponding instructions, the already configured circuit board can be used as a data consolidation terminal for the six PSDs, which can reduce the complexity of the circuit [13].

3) Equipment mechanism design

As shown in Figure 3, the torque-controlled automatic screw tightening equipment consists of a clamping positioning mechanism, a lifting positioning mechanism, a tightening mechanism, a machine base, and an electrical control cabinet.

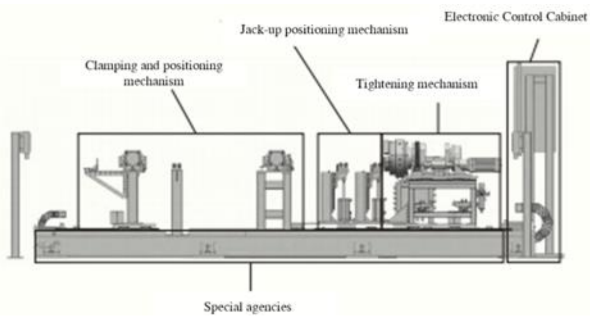

Figure 3: Diagram of Special Aircraft Composition

As shown in Figure 4, the clamping bracket 1 is located on the servo slide of the special aircraft base. When the equipment is running, the workpiece 1 is placed on the support bearing of the clamping positioning mechanism so that the workpiece can only maintain axial movement. The servo slide moves in the direction of clamping bracket 2 with the clamping bracket 1, causing the push plate on clamping bracket 1 to push the workpiece 1 in synchronized movement [14]. When the sensor on clamping bracket 2 detects the end face of the workpiece, the servo slide stops working, and the clamping mechanism on clamping brackets 1 and 2 clamps and positions the workpiece 1.

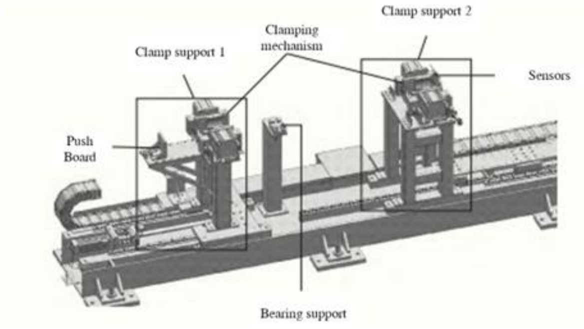

Figure 4: Clamping Positioning Mechanism

As shown in Figure 5, the lift positioning mechanism is installed on the dedicated machine base. When the equipment is in operation, the robotic arm places workpiece 2 on the lift positioning mechanism. The lift positioning mechanism then lifts workpiece 2, aligning it with workpiece 1 in the tightening mechanism to maintain coaxiality.

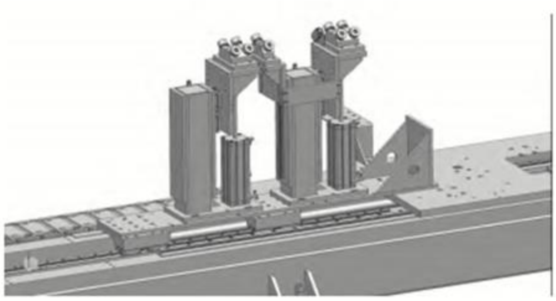

Figure 5: The Lift and Position Mechanism

The tightening mechanism is installed on the servo slide of the dedicated machine base. During equipment operation, the servo slide moves in the direction of workpiece 2 with the tightening mechanism. In this process, workpiece 2 passes through the three-jaw chuck of the tightening mechanism. As the tightening mechanism moves to the clamping position, the three-jaw chuck clamps the workpiece 2, and the power mechanism drives the three-jaw chuck to rotate and tighten the workpiece. When the torque sensor of the tightening mechanism detects that the tightening torque reaches the set value, the power mechanism stops working, and the three-jaw chuck is released. The tightening mechanism returns to its original position.

IV. THE PID CONTROLLER USING THE PSO-GA HYBRID ALGORITHM

A. Basic Principles of PSO-GA Hybrid Algorithm

1) BP neural network structure and algorithm

BP neural network treats the network as a continuous domain, in this network, the input layer and the output layer are any number of sample values at any time, and the value of the output layer of the network can also have any relationship between the value of the input layer, this learning process is called the BP neural network learning process. As a widely used neural network model, BP neural networks consist of an input layer, an output layer, and a hidden layer [15].

1. Input layer. The corresponding output value is generated from the i-th input vector. 2. Output layer. Convert it to input data under the influence of the output value.3. Hidden layer.

Under the effect of the output value, the data is implicitly processed, and the processed result is fed back to the input layer, and the three input layers form one BP neural network. When the input data is propagated by multiple errors in the time domain, it is finally used as the output signal by an error source, that is, through the intermediate information of the input unit and the output group. If the error of this error source is less than the error between the output unit and the cells in the output group, then these cells will vary greatly when calculating the output; If the expected value is exceeded, then the unit is considered to have an error in the input quantity (i.e., there is an error in the input signal) and will no longer be used, and if the expected value is still exceeded, then there will be an error in the output again. By analyzing the relationship between input and output, the relationship between the number of nodes on each hidden layer in the BP network and the output can be obtained [16].

In order to calculate and optimize the BP neural network, the weighting and node criticality of the middle layer are set to control the deviation between the real output of all samples and the expected output in a very low range, and the stability of the interval is ensured by adjusting this interval.

The steps to train an algorithm using a BP neural network are as follows:

1) Training the network.

The training parameters are initialized, and the initial value and training parameters of the model are set on this basis Number.

2) Select.

Select the corresponding training module for training the network pattern, from and be able to meet the learning requirements of the system.

3) When the neural network starts forward transmission.

When broadcasting, keep it in a specific training mode, while computing the neural network.

Output models and prediction models for comparison. If there is an error in the process, it goes directly to the next step; If there are no errors, go back to step 2 and start over.

4) Errors on the same graph level during the reverse transmission of the neural network.

The difference is calculated, and its weights and thresholds are corrected, and then returned to the first.

2) Activation functions

The activation function that is a neuron should be continuous, bounded, and non-valued features, if you want to apply BP neural networks to control systems, in addition to having them [17].

In addition to the above features, the activation function of the neuron node should also satisfy the neural network. The training needs are more complex, and the following three requirements should be met:

1. Numbers should be as simple and easy to calculate as possible, and can be output when there is a bounded value on it.

2. The partial derivative of the activation function should also be as simple and easy to calculate as possible. The reason for this is that partial conductance is also an important parameter for the analysis of neural network training.

3. It should be ensured that the activation function matches the nonlinear system, so as to reduce the network structure. Low difficulty of neural network training. Combined with the above three specific requirements, the hyperbolic tangent function (tanh) is selected. As the hidden layer activation function, the unipolar Sigmoid function is selected as the output. Layer activation function. The tanh function is a bipolar as compared to the Sigmoid function. Function, which has a wider range of output values than a Sigmoid function, and therefore acts as an activation function.

The effect of numbers is also better, and the Sigmoid function can be output as an activation function.

The learning rate is an important factor affecting the change of neural networks, and its main role is to play a role. The role of network training speed control. If the learning rate is high, it will be added.

3) Training rate

Fast network training, but the output may not meet expectations; If the learning rate is low, the network training output can be guaranteed to be the best value, but it also takes more time to train the network .So, usually, it is Experiments to determine the rate of network learning, combined with relevant work experience, Start with a higher learning rate and experiment to reduce the learning rate. Rate until the network reaches stability. 3 PID optimization method based on BP neural network [18].

Combined with the above analysis, after applying the BP neural network to the PID controller, the PID algorithm performed worse than expected in terms of training speed as well as stability. It can obtain an intelligent PID algorithm with excellent performance, and this paper has a right to BP neural network value and learning rate.

4) Learning rate optimization

Through the analysis, it can be seen that the BP neural network emerged during the training process

Problems such as slow convergence and fluctuating oscillations are caused by the learning rate from the beginning to the end. In order to eliminate these problems, the researchers proposed. One can make the neural unit learning rate change gradually with the system adjustment time. however, it only works with individual neural network systems, and does not suitable for fusion systems that combine BP neural networks and control systems. In addition, you can also bind the learning rate to the network weight to make the learning speed. The rate changes with the change of the network weight, so that it can be changed by changing the network weight value to optimize the learning rate. Therefore, this paper adopts the right to adjust the network.

The specific implementation process of the method of decreasing the learning rate by the amount of value change is as follows:

1. Initialize the network, give the weight matrix of the hidden layer and the output layer, and set the science. The learning rate is η, and the accuracy error during network training is set to Emin. The initial learning rate is used to optimize the weight matrix.

2. The adjusted weight matrix is better than the initial matrix, so the learning rate is set to the initial 0.5 times the learning rate, and then adjust the network weight.

3. If the adjusted weight matrix is worse than the initial weight matrix, the learning rate is set it to 2 times the initial learning rate, and then adjust the network weight.

The advantage of using this method is that each time the weight is adjusted, the corresponding learning.

The rate will become larger or smaller, and will eventually stabilize after many optimizations and adjustments to effectively solve the problem of network oscillation.

If the algorithm aims for higher reliability and efficiency, it must choose optimal parameters. For example, one of the parameters that determine the performance in the particle swarm optimization (PSO) algorithm is the inertia weight ω.

$$c_{id}(t+1)=\omega\cdot v_{id}(t)+c_1r_1(p_{id}\ (t)-x_{id}(t))+c_2r_2(p_{gd}(t)-x_{id}(t)) \quad (4\text{-}1)$$

Selection, crossover, and mutation are the essential processes in genetic algorithms. The mutation process can enhance the algorithm's local search capability. Let M be the population size, and fj be the fitness of individual j. The probability formula for the final selection is as follows.

$$P_j = f_j / \sum_{k=1}^{M} f_k \quad (4\text{-}2)$$

The crossover operation determines the better positions with a probability Pc, and the formula is as follows:

$$p_1(t+1)=p_c\cdot p_1(t)+(1-p_c)\cdot p_2(t)\ \ p_2(t+1)=p_c\cdot p_2(t)+(1-p_c)\cdot p_1(t) \quad (4\text{-}3)$$

B. Basic Flow of Particle Swarm Optimization Genetic Hybrid Algorithm

The flow chart of particle swarm optimization genetic hybrid algorithm optimizing PID control is shown in Figure 6. By using the high efficiency of particle swarm optimization (PSO-RRB- to select, cross and mutate genetic operators, the optimal value of population fitness can be obtained until the global optimal solution is found, that is to get the maximum time of the hidden value, and finally achieve the relevant parameters of the PID controller to adjust the goal [19]. The flow chart of PSO genetic hybrid algorithm for PID parameter optimization is as follows: (1) the initial parameter setting of PSO controller is evaluated by the fitness function to make the calculated particle more accord with the actual need, in this way, the genetic operator is calculated by using the fitness value, (2) the error e (t) between the output value and the actual value is analyzed, (3) the relevant input and output data are obtained by calculation, the control parameters of KP, Ki and KD keep corresponding to the output of PID controller.

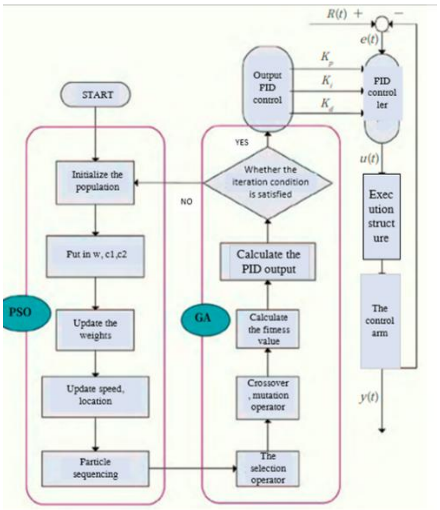

Figure 6: The Flow Chart of PID Control is Optimized by Particle Swarm Optimization Genetic Algorithm

C. System Simulation and Result Analysis

In this paper, genetic algorithm (GA) , particle swarm optimization (PSO) and hybrid particle swarm optimization (PSO) are used to optimize three PID parameters (Kp, Ki, KD) , the maximum speed is 2.6, the selection probability is 0.6, the crossover probability is 0.5, and the mutation probability is 0.09. If the unit step signal is used to load the manipulator, the particle swarm optimization genetic algorithm (PSO) is used to control the PID parameters and the output is shown in Figure 7. It can be seen from the graph that the system is relatively stable and the response time is greatly shortened when the hybrid particle swarm optimization algorithm is used to optimize the PID parameters. The output trajectory tracking curves of PSO-GA hybrid control algorithm and individual PID control are compared with the ideal values, as shown in Figure 8. As can be seen from the graph, the tracking curve of the single PID control output trajectory is relatively large, and there is a certain deviation, the tracking curve of the PSO-GA hybrid control algorithm almost coincides with the ideal output value, the direction of wave is consistent, which also shows that its tracking speed is fast and convergence is good. The simulation data of PID control and PSO-GA hybrid algorithm are shown in Table 1. From the data in the table, it can be seen that the tuning time of PID control optimized by PSO-GA hybrid algorithm is shorter than that of PID control alone. The overshoot of PID control optimized by PSO-GA hybrid algorithm is 8.367%, which is far less than that of PID control alone, it is shown that the PSO-GA hybrid algorithm has higher accuracy and better robustness.

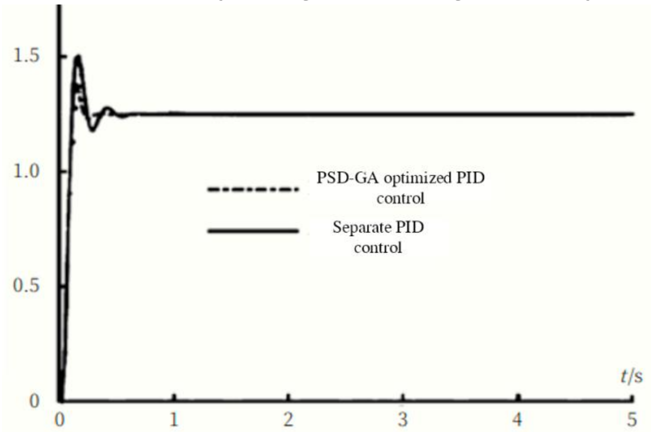

Figure 7: PID Parameters of PSO-GA Algorithm Control Step Response Curve

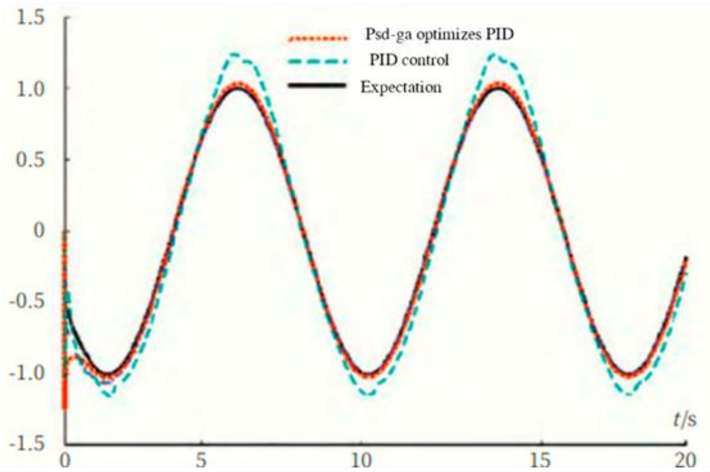

Figure 8: The Output Trajectory Tracking Curve is Compared with the Ideal Value

Table 1: Evaluation Index of the Model

Control model	Kp	Kj	Kd	Overshoot/%	Adjust the time/S
PID	4.235	0.468	11.64	15.74	0.83
PSO-GA PID	5.123	0.154	7.642	8.367	0.37

V. CONCLUSION

In the field of assembly of tubular workpiece, the method of manual fastening is often used in the industry. The problem of low automation rate exists in manual assembly, moreover, manual tightening not only increases the working intensity of the workers, but also can not get the exact tightening torque to judge whether the workpiece is in place, and can not ensure the assembly rate of good products [20]. The design and development of automatic screw tightening device based on torque control, through tightening torque feedback and mechanism control, provides an effective solution for the assembly of some thread-combined workpiece, compared with manual work, its efficiency, quality and stability have been greatly improved, which is an important technical innovation in thread combination of assembly field and fills the gap of automation in this field, and can be applied in similar industries.

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